8.0 WASTEWATER TREATMENT TECHNOLOGY DESCRIPTION

This chapter consists of the following two main parts: Section 8.1, describing the wastewater treatment and sludge handling methods currently in use in the Landfills industry and Section 8.2, presenting a discussion on the performance of treatment systems evaluated by EPA using data collected during engineering site visits and field sampling programs.

8.1   Available BAT and PSES Technologies

The Landfills industry uses a wide variety of technologies for treating wastewater discharges. These technologies can be classified into the following five areas:

		Section
C	Best Management Practices	8.1.1
C	Physical/Chemical Treatment	8.1.2
C	Biological Treatment	8.1.3
C	Sludge Handling	8.1.4
C	Zero Discharge options	8.1.5

The EPA's Detailed Questionnaire obtained information on 14 treatment technologies currently in use in the Landfills industry. Table 8-1 presents the technologies most commonly used by in-scope Subtitle D non-hazardous and Subtitle C hazardous landfill facilities by discharge type. The table reports the percent of landfill facilities which use each treatment technology. In addition, EPA collected detailed information on available technologies from engineering site visits to a number of landfill facilities. The data presented below are based on these data collection efforts.

8.1.1   Best Management Practices

Best management practices with regard to wastewater generation at landfills can be designed to do one of

two things: reduce the volume of leachate produced by the landfill or reduce the toxicity of the leachate produced by the landfill. The volume of leachate generated by a landfill is largely dependent on the annual precipitation that falls within the landfill area, percolates through the landfilled waste, and collects in the leachate collection system. State and Resource Conservation and Recovery Act (RCRA) regulations require closed landfills to install an impermeable cap over the landfill to prevent infiltration of rainwater, which will eventually reduce the volume of wastewater produced by the landfill. Open landfills, however, can similarly use methods to reduce rainwater infiltration to the landfill and, hence, reduce wastewater generation. The open face of the landfill is the active area where solid waste is deposited, compacted, and covered with daily fill. This area can act as a collection point for rainwater. By maintaining a small open face on the landfill, along with using impermeable materials on the closed or inactive sections, a landfill operator can reduce the volume of wastewater collected and produced by an open landfill.

The criteria outlined by the Office of Solid Waste and Emergency Response in 40 CFR § 257, 258, 264, and 265 provide additional controls to reduce the volume and/or toxicity of landfill leachate. 40 CFR Part 257 ("Criteria for Classification of Solid Waste Disposal Facilities and Practices") establishes disposal practices for non-municipal, non-hazardous waste disposal units (including waste disposal units that receive conditionally-exempt small quantity generator waste). In Part 257.3-3(c), the regulations state that a facility shall not cause non-point source pollution of waters of the United States that violates the applicable legal requirements implementing an area or Statewide water quality management plan. 40 CFR Part 258 ("Criteria for Municipal Solid Waste Landfills") requires municipal solid waste landfills to design, construct and maintain run-on/run-off control systems (40 CFR 258.26), cover the disposed solid waste with six inches of earthen material at the end of each operating day (40 CFR 258.21), and subject these facilities to closure criteria, which require a final cover to be applied to cover the wastes (40 CFR 258.60). These requirements greatly reduce the risk of storm water becoming contaminated as a result of direct contact with the deposited solid waste. Subpart N of 40 CFR Part 264 ("Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities") establishes design and operating requirements for hazardous waste landfills. Hazardous waste landfills must design, construct, operate, and

maintain run-on/run-off control systems (264.301(g)) and, if the landfill contains particulate matter which may be subject to wind dispersal, the operator must cover or otherwise manage the landfill to control wind dispersal (264.301(j)). Subpart N of 40 CFR Part 265, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," defines similar controls to those identified above for Part 264 for the control of storm water contamination.

In addition, many municipal solid waste landfills and communities have developed programs to prevent toxic materials from being deposited in landfills. Solid waste generated by households may contain many types of waste which may present an environmental hazard, including paints, pesticides, and batteries. Many communities have developed household hazardous waste collection programs which collect and dispose of these hazardous wastes in an appropriate manner, thus avoiding deposition of hazardous wastes in the municipal landfill and reducing the risks associated with the leachate produced by the landfill.

8.1.2   Physical/Chemical Treatment

8.1.2.1   Equalization

Wastewater and leachate generation rates at landfills vary due to their direct relationship to rainfall, storm water run-on and run-off, ground water entering the waste-containing zone, and the moisture content and absorption capability of the wastes. To allow for the equalization of pollutant loadings and flow rates, leachate and other landfill generated wastewater is often collected prior to treatment in tanks or ponds with sufficient capacity to hold the peak flows generated at the facility. A constant flow is delivered to the treatment system from these holding tanks in order to dampen the variation in hydraulic and pollutant loadings to the wastewater treatment system. This reduction in hydraulic and pollutant variability increases the performance and reliability of down stream treatment systems and can reduce the size of subsequent treatment tanks and chemical or polymer feed rates by reducing the maximum flow rates and concentrations of pollutants. Equalization also lowers the operating costs associated with treatment units by reducing instantaneous treatment capacity demand and by optimizing the amount of treatment chemicals required for a less erratic set of treatment variables. National estimates based on EPA's Detailed Questionnaire data

show that 21 percent of direct and 12 percent of indirect non-hazardous landfill facilities use some form of equalization as part of wastewater treatment systems.

Equalization systems consist of steel or fiberglass holding tanks or lined ponds that provide sufficient capacity to contain peak flow conditions. Detention times are determined using a mass balance equation and are dependent on site-specific generation rates and treatment design criteria. According to data collected by EPA's Detailed Questionnaire, detention times can range from less than a day to 90 days, with a median value of about two days. Equalization systems contain either mechanical mixing systems or aeration systems to enhance the equalization process by keeping the tank contents well mixed and prohibiting the settling of solids.

A breakdown of equalization systems used in the Landfills industry based on the responses to the Detailed Questionnaire is as follows:

Equalization Type	% Non-Hazardous Facilities		% Hazardous Facilities
	Direct	Indirect	Indirect
Unstirred	13	7	0
Mechanically Stirred	>1	<1	0
Aerated	11	6	0

A typical equalization system is shown in Figure 8-1.

8.1.2.2   Neutralization

Wastewater generated by landfills may have a wide range of pH depending on the types of waste deposited in the landfill. In many instances, raw wastewater may require neutralization to eliminate either high or low pH values that may upset a treatment system, such as activated sludge biological treatment. However, landfill facilities also use neutralization systems in conjunction with certain chemical treatment processes, such as chemical precipitation, to adjust the pH of the wastewater to optimize process control. Acids, such as sulfuric acid or hydrochloric acid, are added to reduce pH, and alkalies, such as sodium hydroxide,

are added to raise pH values. Neutralization may be performed in a holding tank, rapid mix tank, or an equalization tank. Typically, neutralization systems at the end of a treatment system are designed to control the pH of the discharge to between 6 and 9. National estimates based on EPA's Detailed Questionnaire data show that 33 percent of indirect hazardous landfills, 6 percent of indirect non-hazardous landfills, and 7 percent of direct non-hazardous landfill facilities employ neutralization as part of wastewater treatment systems using a variety of chemical additives to control pH.

Figure 8-2 presents a flow diagram for a typical neutralization system.

8.1.2.3   Flocculation

Flocculation is a treatment technology used to enhance sedimentation or filtration treatment system performance. Flocculation precedes these processes and usually consists of a rapid mix tank, or in-line mixer, and a flocculation tank. The waste stream is initially mixed while a flocculation chemical is added. Flocculants adhere readily to suspended solids and each other to facilitate gravity sedimentation or filtration. Coagulants can be added to reduce the electrostatic surface charges and enhance the formation of complex hydrous oxides. Coagulation allows for the formation of larger, heavier particles, or flocculants (which usually form in a flocculation chamber), that can settle faster. There are three different types of flocculants commonly used: inorganic electrolytes, natural organic polymers, and synthetic polyelectrolytes. The selection of the specific treatment chemical is highly dependent upon the characteristics and chemical properties of the contaminants. A rapid mix tank is usually designed for a detention time from 15 seconds to several minutes (see reference 3). After mixing, the coagulated wastewater flows to a flocculation basin where slow mixing of the waste occurs. The slow mixing allows for the particles to agglomerate into heavier, more settleable solids. Mixing is provided either by mechanical paddle mixers or by diffused air. Flocculation basins are typically designed for a detention time of 15 to 60 minutes (see reference 3). Since many landfill facilities employ gravity-assisted separation and chemical precipitation as part of wastewater treatment systems, EPA assumes that many of these facilities employ flocculation to enhance system performance.

8.1.2.4   Gravity Assisted Separation

Gravity-assisted separation or sedimentation is a simple, economical, and widely used method for the treatment of landfill wastewater. Clarification systems remove suspended matter, flocculated impurities, and precipitates from wastewater. By allowing the wastewater to become quiescent, the suspended matter, which is heavier than water, can settle to the bottom of the clarifier, forming a sludge blanket which can be removed. This process can occur in specially designed tanks, or in earthen ponds and basins. Clarification systems can also be equipped to allow for the removal of materials lighter than water, such as oils, which are skimmed from the surface and collected for disposal. Sedimentation units at landfills are used as either primary treatment options to remove suspended solids or as a secondary treatment option following a biological or chemical precipitation process. Sedimentation processes are highly sensitive to flow fluctuations and, therefore, usually require equalization at facilities with large flow variations.

Clarifiers can be rectangular, square, or circular in shape. In rectangular or square tanks, wastewater flows from one end of the tank to the other with settled sludge collected into a hopper located at one end of the tank. In circular tanks, flow enters from the center and flows towards the outside edge with sludge collected in a center hopper. Treated wastewater exits the clarifier by flowing over a weir located at the top of the clarifier. Sludge which accumulates at the bottom of the clarifier is periodically removed and is typically stabilized and/or dewatered prior to disposal. National estimates based on EPA's Detailed Questionnaire data suggest that 67 percent of indirect hazardous landfills, 9 percent of indirect non-hazardous landfills, and 27 percent of direct non-hazardous landfill facilities employ some form of gravity-assisted separation as part of wastewater treatment systems.

Flocculation systems are commonly used in conjunction with gravity-assisted clarification systems to improve their solids removal efficiency. Some clarifiers are designed with a center well to introduce flocculants and allow for coagulation in order to improve removal efficiencies. A schematic of a typical clarification system using coagulation and flocculation is shown in Figure 8-3. The main design parameters used in designing a clarifier are the overflow rate, detention time, and the side water depth. Overflow rate

is the measure of the flow as a function of the surface area of the clarifier. Typical design parameters used for both primary and secondary clarifiers are presented below (see reference 7):

Design Parameter	Primary	Secondary
Overflow rate, gpd/sq ft	600-1,000	500-700
Detention time, min	90-150	90-150
Minimum Side water depth, ft	8	10

A variation of conventional clarification process is the chemically-assisted clarification process. Coagulants are added to clarifiers to enhance liquid-solid separation, permitting solids denser than water to settle to the bottom and materials less dense than water (including oil and grease) to flow to the surface. Settled solids form a sludge at the bottom of the clarifier which can be pumped out continuously or intermittently. Oil and grease and other floating materials may be skimmed.

Chemically assisted clarification may be used alone or as part of a more complex treatment process. It also may be used in the following capacities:

C   The first process applied to wastewater containing high levels of settleable suspended solids.

C   The second stage of most biological treatment processes to remove the settleable materials, including microorganisms, from the wastewater; the microorganisms then can be either recycled to the biological reactor or sent to the facility's sludge handling system.

C   The final stage of most chemical precipitation (coagulation/flocculation) processes to remove the inorganic flocs from the wastewater.

As discussed in Chapter 9, chemically-assisted clarification was a component of the model wastewater treatment technology for estimating the BPT engineering costs of compliance and applied in certain cases. In developing regulatory compliance costs, EPA used chemically-assisted clarification processes as an additional polishing process after biological treatment. Chemically- assisted clarification processes consist of both a clarifier and a polymer feed system. For facilities currently with sedimentation following biological

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treatment, EPA provided additional costs only for a polymer feed system. EPA included chemically-assisted clarification systems in the BPT option to aid in the settling process following biological treatment to enhance both TSS and BOD_5 removals through the wastewater treatment process. Higher BOD_5 removals can be obtained by the additional removal of microbial floc in the clarifier. EPA costed facilities for a chemically-assisted clarification system when their current performance for TSS and/or BOD_5 was slightly out of compliance with regulatory levels (up to 10 mg/L for BOD_5 and 50 mg/L for TSS). For instance, if a facility had an aerobic lagoon treatment system and exceeded the regulatory level for TSS by 20 mg/L, EPA costed the facility for a chemically-assisted clarification system.

Although no landfill facilities in EPA's database reported using chemical addition, chemically-assisted clarification is a proven technology for the removal of BOD_5 and TSS in a variety of industrial categories (see reference 19).

National estimates indicate that less than one percent of direct and indirect non-hazardous landfills use an alternative clarification system design based on corrugated plate interceptor (CPI) technology. These systems include a series of small (approximately two inch square) inclined tubes in the clarification settling zone. The suspended matter must only travel a short distance, when settling or floating, before they reach a surface of the tube. At the tubes' surface, the suspended matter further coagulate. Because of the increased surface area provided by the inclined tubes, CPI units can have much smaller settling chambers than standard clarifiers.
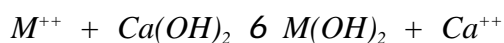
8.1.2.5   Chemical Precipitation

Chemical precipitation is used for the removal of metal compounds from wastewater. In the chemical precipitation process, soluble metallic ions and certain anions found in landfill wastewater are converted to insoluble forms, which precipitate from solution. Most metals are relatively insoluble as hydroxides, sulfides, or carbonates. Coagulation processes are used in conjunction with precipitation to facilitate removal by agglomeration of suspended and colloidal materials. The precipitated metals are subsequently

removed from the wastewater stream by liquid filtration or clarification (or some other form of gravity assisted separation). Other treatment processes such as equalization, chemical oxidation, or reduction (e.g., hexavalent chromium reduction) usually precede the chemical precipitation process. The performance of the chemical precipitation process is affected by chemical interactions, temperature, pH, solubility of waste contaminants, and mixing effects.

Common precipitates used at landfills facilities include lime, sodium hydroxide, soda ash, sodium sulfide, and alum. Other chemicals used in the precipitation process for pH adjustment and/or coagulation include sulfuric and phosphoric acid, ferric chloride, and polyelectrolytes. Often, facilities use a combination of these chemicals. Precipitation using sodium hydroxide or lime is the conventional method of removing metals from wastewater at landfill facilities. Hydroxide precipitation is effective in removing metals such as antimony, arsenic, chromium, copper, lead, mercury, nickel, and zinc. However, sulfide precipitation is used, instead of hydroxide precipitation, to remove specific metal ions such as mercury, lead, and silver. Carbonate precipitation is another method of chemical precipitation and is used primarily to remove antimony and lead. Use of alum as a precipitant/coagulant agent results in the formation of aluminum hydroxides in wastewater containing calcium or magnesium bicarbonate. Aluminum hydroxide is an insoluble gelatinous floc which settles slowly and entraps suspended materials. It is effective for removing metals such as arsenic and cadmium.

Since lime is less expensive than caustic (sodium hydroxide), it is more frequently used at landfill facilities employing hydroxide precipitation. However, lime is more difficult to handle and feed, as it must be slaked, slurried, and mixed and can often plug feed system lines. Lime precipitation also produces a larger volume of sludge. The reaction mechanism for precipitation of a divalent metal using lime is shown below:

$$M^{++} + Ca(OH)_2 \; \textbf{6} \; M(OH)_2 + Ca^{++}$$

And, the reaction mechanism for precipitation of a divalent metal using sodium hydroxide is:

$$M^{++} + 2NaOH \; 6 \; M(OH)_2 + 2Na^{++}$$
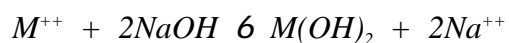
In addition to the type of treatment chemical chosen, an important design factor in the chemical precipitation operation is pH. Metal hydroxides are amphoteric, meaning they can react chemically as acids or bases. As such, their solubilities increase toward both lower and higher pH levels. Therefore, there is an optimum pH for precipitation for each metal, which corresponds to its point of minimum solubility. Figure 8-4 presents calculated solubilities of metal hydroxides. For example, as demonstrated on this figure, the optimum pH range where zinc is least soluble is 8 to 10.

Another key consideration in a chemical precipitation application is the detention time in the sedimentation phase of the process. The optimal detention time is dependent on the wastewater being treated and the desired effluent quality.

The first step of a chemical precipitation process is pH adjustment and the addition of coagulants. This process usually takes place in separate mixing and flocculation tanks. After mixing the wastewater with treatment chemicals, the resultant mixture agglomerates in the flocculation tank, and is mixed slowly by either mechanical means, such as mixers or recirculation pumping. The wastewater then undergoes a separation/dewatering process, such as clarification or filtration, where the precipitated metals are removed from solution. In a clarification system, a flocculant, such as a polymer, is sometimes added to aid in the settling process. The resulting sludge from the clarifier or filter must be further treated, disposed, or recycled.

National estimates based on EPA's database indicate that 33 percent of indirect hazardous landfills, 5 percent of indirect non-hazardous landfills, and 9 percent of direct non-hazardous landfill facilities employ chemical precipitation as part of wastewater treatment systems. A typical chemical precipitation system is presented in Figure 8-5.

8.1.2.5.1   Iron (Fe) Coprecipitation

One cost-effective approach to remove metals is the iron adsorption and coprecipitation process. This process involves adding an iron salt, such as ferric chloride or ferric sulfate, to wastewater (unless it already contains sufficient quantities of dissolved iron) to form iron hydroxide precipitate [$Fe(OH)_3(s)$]. Above a pH of 4, the formation of this amorphous precipitate occurs rapidly, causing entrapment of many dissolved and suspended forms of various metals. This "sweep floc" results in the formation of a large quantity of solids (sludge) that can be gravity separated in a conventional clarifier (see reference 57).

8.1.2.6   Chemical Oxidation/Reduction

Chemical oxidation treatment processes can be used to remove ammonia, to oxidize cyanide, to reduce the concentration of residual organics, and to reduce the bacterial and viral content of wastewater. Both chlorine and ozone are two chemicals that are commonly used to destroy residual organics in wastewater. When these chemicals are used for this purpose, disinfection of the wastewater is usually an added benefit. A further benefit of using ozone is the removal of color. Ozone can also be combined with hydrogen peroxide to remove organic compounds in contaminated ground water. Another use of oxidation is for the conversion of pollutants to end products or to intermediate products that are more readily biodegradable or removed more readily by adsorption. National estimates based on the Detailed Questionnaire data show that 33 percent of indirect hazardous landfills, 11 percent of direct non-hazardous landfills, and less than one percent of indirect non-hazardous landfill facilities use chemical oxidation units as part of wastewater treatment systems.

Chemical oxidation is a chemical reaction process in which one or more electrons are transferred from the chemical being oxidized to the chemical initiating the transfer (the oxidizing agent). The electron acceptor may be another element, including an oxygen molecule, or it may be a chemical species containing oxygen, such as hydrogen peroxide, chlorine dioxide (see Section 8.1.2.6.1), permanganate, or ozone. This process is also effective in destroying cyanide and toxic organic compounds. Figure 8-6 presents a process schematic for a chemical oxidation system that uses an alkaline chlorination process.

Chemical oxidation is a potential treatment option for the removal of certain organic pollutants from leachate or ground water. The amount of oxidant required in practice is generally greater than the theoretical mass calculated. The reasons for this are numerous and include incomplete oxidant consumption and oxidant demand caused by other species in solution. Oxidation reactions are catalysts and pH dependent; hence, pH control is an important design variable. For many facilities utilizing chemical oxidation, partial oxidation of organics, followed by additional treatment options, may be more efficient and cost effective than using a complete oxidation treatment scheme alone.

According to the Detailed Questionnaire data, landfill facilities use chemical oxidation processes to treat cyanide-bearing wastes and organic pollutants and as a disinfectant. When treating cyanide or organic wastes, these processes use strong oxidizing chemicals, such as chlorine in elemental or hypochlorite salt form. As a disinfection process, an oxidant (usually chlorine) is added to the wastewater in the form of either chlorine dioxide or sodium hypochlorite (see Section 8.1.2.6.1). Other disinfectant chemicals include ozone, hydrogen peroxide, sulfur dioxide, and calcium hypochlorite. Once the oxidant is mixed with the wastewater, sufficient detention time (usually 30 minutes) is allowed for the disinfecting reactions to occur (see reference 7).

Chemical reduction processes involve a chemical reaction in which electrons are transferred from one chemical to another to reduce the chemical state of a contaminant. The main application of chemical reduction in leachate treatment is the reduction of hexavalent chromium to trivalent chromium. Chromium reduction is necessary due to the inability of hexavalent chromium to form a hydroxide, and enables the trivalent chromium to be precipitated from solution in conjunction with other metallic salts. Figure 8-7 presents a flow diagram of a chromium reduction system. Sulfur dioxide, sodium bisulfate, sodium metabisulfate, and ferrous sulfate are typical reducing agents used at landfill facilities.

8.1.2.6.1   Breakpoint Chlorination

Breakpoint chlorination, in wide use as a wastewater treatment technology, is a physical-chemical means

of removing ammonia from wastewater. Chlorine is added to process waters until the chlorine demand of the wastewater has been satisfied. At this point, the total dissolved residual chlorine has reached a minimum (the breakpoint) and the ammonia has been oxidized to form nitrogen gas and hydrochloric acid. EPA evaluated breakpoint chlorination as an alternative to biological treatment for removing ammonia at landfill facilities with low BOD concentrations. EPA concluded that these facilities may have difficulty operating biological treatment systems due to the low organic content of the wastewater.

The most common chlorine compounds used in wastewater treatment plants are chlorine gas (Cl_2), calcium hypochlorite [$Ca(OCl)_2$], sodium hypochlorite ($NaOCl$), and chlorine dioxide (ClO_2). Calcium and sodium hypochlorite are most often used in very small treatment plants, such as package plants, where simplicity and safety are far more important than cost. Sodium hypochlorite is often used at large facilities, primarily for reasons of safety as influenced by local conditions. Because chlorine dioxide does not react with ammonia, it is also used in a number of treatment facilities where interferences with ammonia are a concern.

The maintenance of a chlorine residual for the purpose of wastewater disinfection is complicated by the fact that free chlorine not only reacts with ammonia, but is also a strong oxidizing agent. As chlorine is added, readily oxidizable substances, such as Fe^{+2}, Mn^{+2}, H_2S, and organic matter, react with the chlorine and reduce most of it to the chloride ion. After meeting this immediate demand, the chlorine continues to react with the ammonia to form chloramines. Additional chlorine will cause some of the chloramines to be converted to nitrogen trichloride (NCl_3), the remaining will be oxidized to nitrous oxide (N_2O) and nitrogen (N_2), and the chlorine will be reduced to the chloride ion. With continued addition of chlorine, most of the chloramines will be oxidized at the breakpoint. Continued addition of chlorine past the breakpoint will result in a directly proportional increase in the free available chlorine (unreacted hypochlorite). The main reason for adding enough chlorine to obtain a free chlorine residual is that usually disinfection can then be ensured (see reference 56).

8.1.2.7 Air Stripping

Stripping is an effective treatment method for removing dissolved volatile organic compounds from wastewater. The removal is accomplished by passing air or steam through the agitated waste stream. The process results in a contaminated off-gas stream which, depending upon the air emissions standards, usually requires air pollution control equipment. National estimates based on EPA's Detailed Questionnaire data indicate that 4 percent of direct and approximately one percent of indirect non-hazardous landfill facilities use air stripping as part of wastewater treatment systems.

The driving force of air stripping mass-transfer operation is the difference in concentrations between the air and liquid streams. Pollutants are transferred from the more concentrated wastewater stream to the less concentrated air stream until equilibrium is reached. This equilibrium relationship is defined by Henry's Law. The strippability of a pollutant is expressed as its Henry's Law Constant, which is a function of its volatility and solubility.

Air stripping (or steam stripping) can be performed in tanks or in spray or packed towers. Treatment in packed towers is the most efficient application. The packing typically consists of plastic rings or saddles. The two types of towers that are commonly used, cross-flow and countercurrent, differ in design only in the location of the air inlets. In the cross-flow tower, the air is drawn through the sides for the total length of the packing. The countercurrent tower draws its entire air flow from the bottom. The cross-flow towers have been found to be more susceptible to scaling problems and are less efficient than countercurrent towers.

Figure 8-8 presents a flow diagram of a countercurrent air stripper.

8.1.2.8 Filtration

Filtration is a method for separating solid particles from a fluid through the use of a porous medium. The driving force in filtration is a pressure gradient caused by gravity, centrifugal force, or a vacuum. Filtration

treatment processes can be used at landfills to remove solids from wastewater after physical/chemical or biological treatment or as the primary source of leachate treatment. Filtration processes include a broad range of media and membrane separation technologies from ultrafiltration to reverse osmosis. To aid in removal, the filter medium may be precoated with a filtration aid such as ground cellulose or diatomaceous earth.

National estimates based on the Detailed Questionnaire data indicate that 11 percent of direct and two percent of indirect non-hazardous landfill facilities have some form of filtration as part of wastewater treatment systems, including the following:

Type of Filtration System	% Non-Hazardous Facilities	
	Direct	Indirect
Sand	6	<1
Diatomaceous earth	0	<1
Granular multimedia	6	<1
Membrane	0	1
Fabric	0	<1

Dissolved compounds in landfill wastewater are sometimes pretreated to convert the compound to an insoluble solid particle prior to filtration. Polymers are sometimes injected into the filter feed piping downstream of feed pumps to enhance flocculation of smaller flocs that may escape an upstream clarifier. Pretreatment for iron and calcium is sometimes necessary to prevent fouling and scaling.

The following sections discuss the various types of filtration in use at landfills facilities.

8.1.2.8.1   Sand Filtration

Sand filtration processes consist of either a fixed or moving bed of media that traps and removes suspended solids from water passing through the media. There are two types of fixed sand bed filters: pressure and gravity. Pressure filters contain media in an enclosed, watertight pressure vessel and require a feed pump

to force the water through the media. A gravity filter operates on the basis of differential pressure of a static head of water above the media, which causes flow through the filter. Filter loading rates for sand filters are typically between 2 to 6 gpm/sq ft (see reference 7).

All fixed media filters have influent and effluent distribution systems consisting of pipes and fittings. Strainers in the tank bottom are usually stainless steel screens. Layers of uniformly sized gravel also serve as bottom strainers and as a support for the sand. For both types of filters, the bed builds up head loss over time. Head loss is a measure of solids trapped in the filter. As the filter becomes filled with trapped solids, the efficiency of the filtration process falls off, and the filter must be backwashed. Filters are backwashed by reversing the flow so that the solids in the media are dislodged and can exit the filter; sometimes air is dispersed into the sand bed to scour the media.

Fixed-bed filters can be automatically backwashed when the differential pressure exceeds a preset limit or when a timer starts the backwash cycle. Powered valves and a backwash pump are activated and controlled by adjustable cam timers or electronic programmable-logic controllers to perform the backwash function. A supply of clean backwash water is required. Backwash water and trapped particles are commonly discharged to an equalization tank upstream of the wastewater treatment system's primary clarifier or screen for removal.

Moving bed filters use an air lift pump and draft tube to recirculate sand from the filter bottom to the top of the filter vessel, which is usually open at the top. Dirty water entering the filter at the bottom must travel upward, countercurrently, through the downward moving fluidized sand bed. Particles are strained from the rising water and carried downward with the sand. Due to the difference in specific gravity, the lighter particles are removed from the filter when the sand is recycled through a separation box at the top of the filter or in a remote location. The heavier sand falls back into the filter, while the lighter particles flow over a weir to waste. Moving bed filters are continuously backwashed and have a constant rate of effluent flow.

8.1.2.8.2   Diatomaceous Earth

These filtration systems use diatomaceous earth, a natural substance, as a precoat on either a vacuum or pressure filter arrangement to enhance removal efficiencies. In these instances, the diatomaceous earth is placed as a thin layer over a screen. The wastewater then is passed through the layer of earth and screen, with the suspended particles being filtered. A vacuum can be drawn across the screen, or pressure applied to the wastewater to help the liquid pass through the filter medium.

8.1.2.8.3   Multimedia Filtration

Multimedia, or granular bed, filtration is used for achieving supplemental removal of residual suspended solids from the effluent of chemical or biological treatment processes. These filters can be operated either by gravity or under pressure in a vessel. In granular-bed filtration, the wastewater stream is sent through a bed containing one or more layers of different granular materials. The solids are retained in the voids between the media particles while the wastewater passes through the bed. Typical media used in granular-bed filters include anthracite coal, sand, and garnet. These media can be used alone, such as in sand filtration, or in a multimedia combination. Multimedia filters are designed such that the individual layers of media remain fairly discrete. This is accomplished by selecting appropriate filter loading rates, media grain size, and bed density. Hydraulic loading rates for a multimedia filter are between 4 to 10 gpm/sq ft (see reference 7).

A multimedia filter operates with the finer, denser media at the bottom and the coarser, less dense media at the top. A common arrangement is garnet at the bottom of the bed, sand in the middle, and anthracite coal at the top. Some mixing of these layers occurs. During filtration, the removal of the suspended solids is accomplished by a complex process involving one or more mechanisms, such as straining, sedimentation, interception, impaction, and adsorption. The medium size is the principal characteristic that affects the filtration operation. If the medium is too small, much of the driving force will be wasted in overcoming the frictional resistance of the filter bed. If the medium is too large, small particles will travel through the bed, preventing optimum filtration.

The flow pattern of multimedia filters is usually top-to-bottom. Upflow filters, horizontal filters, and biflow filters are also used. A top-to-bottom multimedia filter is represented in Figure 8-9.

8.1.2.8.4   Membrane Filtration

Membrane filtration systems employ a semi-permeable membrane and a pressure differential. Both ultrafiltration and reverse osmosis are commonly used membrane filtration processes.

8.1.2.8.4.1   Ultrafiltration

Ultrafiltration uses a semipermeable microporous membrane, through which the wastewater is passed under pressure. Water and low molecular weight solutes, such as salts and surfactants, pass through the membrane and are removed as permeate. Emulsified oils and suspended solids are rejected by the membrane and removed with some of the wastewater as a concentrated liquid. The concentrate is recirculated through the membrane unit until the flow of permeate drops. The permeate can either be discharged or passed along to another treatment unit. The concentrate is contained and held for further treatment or disposal. Several types of ultrafiltration membranes configurations are available: tubular, spiral wound, hollow fiber, and plate-and-frame. A typical ultrafiltration system is presented in Figure 8-10.

Ultrafiltration is commonly used for the treatment of metal-bearing and oily wastewater. It can remove substances with molecular weights greater than 500, including suspended solids, oil and grease, large organic molecules, and complexed heavy metals (see reference 8). Ultrafiltration is used when the solute molecules are greater than ten times the size of the solvent molecules and less than one-half micron. The primary design consideration in ultrafiltration is the membrane selection. A membrane pore size is chosen based on the size of the contaminant particles targeted for removal. Other design parameters to be considered are the solids concentration, viscosity, and temperature of the feed stream, and the membrane permeability and thickness.

8.1.2.8.4.2   Reverse Osmosis

Reverse osmosis is a separation process that uses selective semipermeable membranes to remove dissolved solids, such as metal salts, from water. The membranes are more permeable to water than to contaminants or impurities. The wastewater is forced through the membrane at an applied pressure that exceeds the osmotic pressure caused by the dissolved solids. Molecules of water pass through the membrane as permeate while contaminants are flushed along the surface of the membrane and exit as concentrate. The concentrate flow from a reverse osmosis system ranges from 10 to 50 percent of the feed flow, with concentrations of dissolved solids and contaminants approaching 10 times that of the feed water (see reference 6). The percentage of permeate that passes through the membranes is a function of operating pressure, membrane type, and concentration of the contaminants in the feed.

Cellulose acetate, aromatic polyamide, and thin-film composites are commonly used membrane materials. Reverse osmosis membranes are configured into tubular, spiral wound, hollow fiber, or plate-and-frame modules. Modules are inserted into long pressure vessels that can hold one or more modules. Reverse osmosis systems consist of a pretreatment pump, a high pressure feed pump, one or more pressure vessels, controls, and instrumentation. A tubular reverse osmosis module is shown in Figure 8-11.

Membranes have a limited life depending upon application and are replaced when cleaning is no longer effective. Membranes can be cleaned manually or chemically by recirculating the cleaning solution through the membranes to restore performance. Membranes can also be removed from the reverse osmosis system and sent off site for flushing and rejuvenation. Membranes are replaced when cleaning is no longer effective.

Membrane pore sizes for a typical reverse osmosis system range from 0.0005 to 0.002 microns, while pressures of 300 to 400 psi are usually required (see reference 39). Therefore, reverse osmosis feed-water needs to be very low in turbidity. Pretreatment of landfill wastewater prior to reverse osmosis treatment may be necessary, including chemical addition and clarification, or cartridge filtration using 5 micron filters

to remove suspended particulates from the influent in order to protect pumps and membranes. Carbon adsorption is recommended as pretreatment for membranes sensitive to chlorine. Biofouling can be prevented by chlorination and dechlorination of the feed water. To maintain the solubility of metals such as calcium, magnesium, and iron, the pH can be adjusted with acid. Aside from pH adjustment, chemical requirements include the following: bactericide, dechlorination, and chelating agents.

One variation of conventional reverse osmosis technology used at landfill facilities is an innovative membrane separation technology using disc tube modules. This innovative process is designed to treat liquid waste that is higher in dissolved solids content, turbidity, and contaminant levels than waste treated by conventional membrane separation processes. This process also reduces the potential for membrane fouling and scaling, allowing it to be the primary treatment for waste streams such as landfill leachate.

The disc tube membrane module features larger feed-flow channels and a higher feed-flow velocity than typical membrane separation systems (see reference 48). These characteristics allow the disc tube module greater tolerance for dissolved solids and turbidity and a greater resistance to membrane fouling and scaling. The high flow velocity, short feed-water path across each membrane, and the circuitous flow path create turbulent mixing reducing boundary layer effects, and minimizing membrane fouling and scaling.

Membrane material for the disc tube module is formed into a cushion with a porous spacer material on the inside. The membrane cushions are alternately stacked with hydraulic discs on a tension rod. The hydraulic disks support the membranes and provide the flow channels for the feed liquid to pass over the membranes. After passing through the membrane material, permeate flows through collection channels to a product recovery tank. A stack of cushions and disks is housed in a pressure vessel. The number of disks per module, number of modules, and the membrane materials can be varied to suit the application. Modules are typically combined in a treatment unit or stage. Disc tube module units can be connected in series to improve permeate water quality or in parallel to increase system treatment capacity (see reference 48).

Like all membrane separation processes, reverse osmosis technology reduces the volume of the waste. The degree of volume reduction is dependent on the waste characteristics and the system design. Reverse osmosis technology can treat liquid waste streams containing low molecular weight volatile and semivolatile organics, metals, and other inorganic compounds.

8.1.2.8.5   Fabric Filters

Fabric filters consist of a vessel that contains a cloth or paper barrier through which the wastewater must pass. The suspended matter is screened by the fabric and the effectiveness of the filter depends on the mesh size of the fabric. Fabric filters can either be backwashed or built as disposable units.

For waters having less than 10 mg/L suspended solids, cartridge fabric filters may be cost effective. Cartridge filters have very low capital cost and can remove particles of 1 micron or larger (see reference 39). Using two-stage cartridge filters (coarse and fine) in series extends the life of the fine cartridge. Disposable or backwashable bag filters also are available and may be quite cost effective for certain applications. Typically, these fabric filters are used to remove suspended solids prior to other filtration systems to protect membranes and equipment and reduce solids fouling.

8.1.2.9   Carbon Adsorption

Activated-carbon adsorption is a physical separation process in which organic and inorganic materials are removed from wastewater by sorption, or attraction, and accumulation of the compounds on the surface of the carbon granules. This process is commonly referred to as granular activated carbon adsorption. While the primary removal mechanism is adsorption, biological degradation and filtration are additional pollutant removal mechanisms provided by the activated- carbon filter. Adsorption capacities of 0.5 to 10 percent by weight are typical in industrial applications (see reference 5). Spent carbon can either be regenerated on site, by processes such as wet-air oxidation or steam stripping, or, for smaller operations, be regenerated off site or sent directly for disposal. Vendors of carbon can exchange spent carbon with fresh carbon under contract.

Activated-carbon systems consist of a vessel containing a bed of carbon (usually 4 to 12 feet in depth), whereby the wastewater is either passed upflow or downflow through the filter bed (see reference 6). Carbon vessels are typically operated under pressure, though some designs use gravity beds. For smaller applications, granular activated carbon systems also are available in canister systems, which can be readily changed-out and sent for off-site regeneration.

Often more than one carbon vessel is used in series, such that the first column can be used until the carbon is "exhausted" before it is regenerated. The partially-exhausted second column is then used as the first column and another column is rotated behind it to provide polishing. Up to three columns are typically used in a rotating fashion. When all of the available adsorption sites on the granular activated carbon are occupied, a rise in organic concentrations is observed in the effluent leaving the vessel. At this point the granular activated carbon in the vessel is saturated and is said to have reached break-through.

The key design parameter is the adsorption capacity of the granular activated carbon. This is a measure of the mass of contaminant adsorbed per unit mass of carbon and is a function of the chemical compounds being removed, type of carbon used, and process and operating conditions. The volume of carbon required is based upon the COD and/or pollutant-specific concentrations in the wastewater to be treated and desired frequency of carbon change-outs. The vessel is typically designed for an empty bed contact time of 15 to 60 minutes (see reference 5). Non-polar, high molecular weight organics with low solubility are readily adsorbed using GAC. Certain organic compounds have a competitive advantage for adsorption onto GAC, which results in compounds being preferentially adsorbed or causing other less competitive compounds to be desorbed from the GAC. Most organic compounds and some metals typically found in landfill leachate are effectively removed using GAC.

National estimates based on EPA's Detailed Questionnaire data indicate that greater than one percent of indirect and greater than one percent of direct non-hazardous landfill facilities employ carbon adsorption

as part of wastewater treatment systems. Figure 8-12 presents a flow diagram of a typical carbon adsorption vessel.

8.1.2.10   Ion Exchange

Ion exchange is an adsorption process that uses a resin media to remove contaminants from wastewater. Ion exchange is commonly used for the removal of heavy metals from relatively low-concentration waste streams. A key advantage of the ion exchange process is that it allows for the recovery and reuse of the metals in a wastewater. Ion exchange also can be designed to be selective to certain metals and can provide effective removal from wastewater having high concentrations of background compounds such as iron, magnesium, and calcium. A disadvantage is that the resins can be fouled by oils and heavy polymers. Pretreatment for ground water or leachate treated by an ion exchange system typically includes a cartridge filtration unit. Additional tanks and pumps are required for regeneration, chemical feed, and collection of spent solution.

In an ion exchange system, the wastewater stream is passed through a bed of resin. The resin contains bound groups of ionic charge on its surface, which are exchanged for ions of the same charge in the wastewater. Resins are classified by type, either cationic or anionic. The selection of a resin is dependent upon the wastewater contaminant to be removed. Cation resins adsorb metals, while anion resins adsorb such contaminants as nitrate and sulfate. A commonly-used resin is polystyrene copolymerized with divinylbenzene. Key parameters for designing an ion-exchange system include a resin bed loading rate of 2 to 4 gallons per minute per cubic foot, and a pressure vessel diameter providing for a cross-sectional area loading rate of 5 to 8 gallons per minute per square foot (see reference 5).

The ion exchange process involves the following four steps: treatment, backwash, regeneration, and rinse. During the treatment step, wastewater is passed through the resin bed. The ion exchange process continues until pollutant breakthrough occurs. The resin is then backwashed to clean the bed and to remove suspended solids. During the regeneration step, the resin is contacted with either an acidic or alkaline

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solution containing the ion originally present in the resin. This "reverses" the ion exchange process and removes the ions that were originally present in the wastewater and were retained by the resin. The bed is then rinsed to remove residual regenerating solution. The resulting contaminated regenerating solution must be further processed for reuse or disposal. Depending upon system size and economics, some facilities choose to remove the spent resin and replace it with resin regenerated off-site instead of regenerating the resin in-place.

Ion exchange equipment ranges from simple, inexpensive systems such as domestic water softeners, to large, continuous industrial applications. A common industrial setup is fixed-bed resin in a vertical column, where the resin is regenerated in-place. Other operating modes include batch and fluidized bed. These systems can be designed so that the regenerant flow is concurrent or countercurrent to the treatment flow. A countercurrent design, although more complex to operate, provides a higher treatment efficiency. The beds can contain a single type of resin for selective treatment, or the beds can be mixed to provide for more complete deionization of the waste stream. Often, individual beds containing different resins are arranged in series, which makes regeneration easier than in the mixed bed system.

National estimates based on the Detailed Questionnaire data show that less than one percent of indirect non-hazardous landfills employ some form of ion exchange as part of wastewater treatment systems. Figure 8-13 presents a flow diagram of a typical ion exchange setup, fixed-bed resin in a vertical column.

8.1.3   Biological Treatment

Biological treatment uses microbes which consume, and thereby destroy, organic compounds as a food source. Leachate from landfills can contain large quantities of organic materials that can be readily stabilized using biological treatment processes. In addition to the carbon food source supplied by the organic pollutants, the microbes also require energy and supplemental nutrients for growth, such as nitrogen and phosphorus. There are several different classes of microbes that are commonly used in the biological treatment of organic bearing wastes. Aerobic microbes require oxygen to grow, whereas anaerobic

microbes grow in the absence of oxygen. An adaptive type of anaerobic microbe, called a facultative anaerobe, can grow with or without oxygen.

The success of biological treatment in treating wastewater is dependent on several factors, such as the pH and temperature of the wastewater, the nature of the pollutants, the nutrient requirements of the microbes, the presence of other inhibiting pollutants (such as toxic heavy metals), and variations in the feed stream loading.

Aerobic biological treatment systems utilize an acclimated community of microorganisms to degrade, coagulate, and remove organic and other contaminants from wastewater. Organic contaminants in the wastewater are used by the treatment organisms for biological synthesis and growth, with a small portion for cellular maintenance. Resulting products from biological treatment include cellular biomass, carbon dioxide, water and, sometimes, the nondegradable fraction of the organic material.

In the biological treatment process, wastewater is mixed or introduced to the biomass. The microorganisms responsible for stabilization can be maintained in suspended form or can be attached to a solid media. Examples of the suspended growth biological treatment systems include various activated sludge treatment processes and aerobic lagoons. Biological treatment processes which employ the use of fixed film media include trickling filtration, biotowers, and rotating biological contactors.

Anaerobic biological treatment systems can degrade organic matter in wastewater and ultimately convert carbonaceous material into methane and carbon dioxide. Anaerobic systems have been shown to be most effective for high strength leachate (COD over 4,000 mg/L) and for wastewater containing refractory contaminants because of effectiveness of methanotropic microorganisms in metabolizing these compounds. A disadvantage to anaerobic treatment systems is the sensitivity of the methanotropic microorganisms to certain toxic substances.

Initially, in an anaerobic treatment process, the complex organic matter in the raw waste stream is converted to soluble organics by extra-cellular enzymes. This step facilitates the later conversion of soluble organic matter into simple organic acids. The final step involves the conversion of organic acids into methane and carbon dioxide. The bacteria responsible for the conversions have very slow growth rates. In addition, methanotropic bacteria are very sensitive to environmental conditions, require the complete absence of oxygen, a narrow pH range (6.5 to 7.5), and can be readily inhibited by the presence of toxic compounds such as certain heavy metals.

The table below presents EPA's estimated number of landfill facilities that use variations of biological treatment as part of landfill wastewater treatment systems:

Type of Biological Treatment	% Non-Hazardous Facilities		% Hazardous Facilities
	Direct	Indirect	Indirect
Activated Sludge	8	1	33
Aerobic Lagoon Systems	7	3	0
Facultative Lagoons	7	<1	0
Trickling Filters	0	0	0
Anaerobic Systems	2	<1	0
Powdered Activated Carbon Treatment (PACT)*	>1	<1	0
* with Activated Sludge			
Nitrification Systems	2	<1	0
Rotating Biological Contactors (RBCs)	0	0	0
Sequencing Batch Reactors (SBRs)	>1	0	33
Denitrification Systems	>1	0	0
Other+	13	0	0

+ includes aerated submerged fixed film and wetlands

The following sections present a discussion of biological treatment systems in use at landfill facilities.

8.1.3.1 Lagoon Systems

A lagoon, stabilization pond, or oxidation pond is a body of water contained in an earthen dike and designed for biological treatment. While in the lagoon, wastewater is treated to reduce degradable organics through biodegradation and reduce suspended solids through sedimentation. The biological process taking

place in the lagoon can be aerobic, anaerobic, or both (facultative), depending on the design. Because of the low construction and operating costs, lagoons offer a financial advantage over other treatment methods and are popular where sufficient land is available at reasonable cost.

Lagoons are used in wastewater treatment for stabilization of suspended, dissolved, and colloidal organics either as a main biological treatment process or as a polishing treatment process following other biological treatment systems. Aerobic, facultative, and aerated lagoons are generally used for wastewater of low and medium organic strength. High-strength wastewater and wastewater of variable strength often are treated by a series of lagoons. A common configuration is an anaerobic lagoon, followed by a facultative lagoon and an aerobic lagoon.

The performance of lagoons in removing degradable organics depends on detention time, temperature, and the nature of the waste. Aerated lagoons generally provide a high degree of BOD_5 reduction more consistently than aerobic or facultative lagoons. Typical problems associated with lagoons are excessive algae growth, offensive odors from anaerobic lagoons if sulfates are present and the lagoon is not covered, and seasonal variations in effluent quality. The major classes of lagoons that are based on the nature of biological activities are discussed below.

Aerobic lagoons depend on algae photosynthesis and natural aeration to assist in the biological activity. These shallow lagoons (3 to 4 feet in depth) rely on both the natural oxygen transfer occurring through the surface area of the lagoon and the production of oxygen from photosynthetic algae. Aerobic lagoons are generally suitable for treating low- to medium-strength landfill leachates due to the recommended smaller food to mass ratios. Because of this design limitation, aerobic lagoons are used in combination with other lagoons to treat higher-strength landfill leachates to achieve additional organic removal following conventional wastewater treatment processes. The typical hydraulic detention time for an aerobic lagoon is 10 to 40 days, with an organic loading of 60 to 120 pounds of BOD_5 per day per acre (see reference 7).

A variation of the aerobic lagoon is the aerated lagoon. These lagoons do not depend on algae and sunlight to furnish dissolved oxygen, but require additional oxygen to be introduced to prevent anaerobic conditions. In these systems, mechanical or diffused aeration devices are used in the lagoons for oxygen transfer and to create some degree of mixing (see Figure 8-14). Due to this mixing, additional suspended solids removal in the effluent from the lagoon may be required. The recommended hydraulic detention time is 3 to 20 days, with an organic loading of 20 to 400 pounds of BOD_5 per day per acre (see reference 7). Based on these higher design loading rates, aerated lagoons are well suited for treatment of medium-strength landfill leachates.

Aerated lagoons are relatively simple to operate. The influent is fed into the basin where it is mixed and aerated with the lagoon contents. Settled sludge is not routinely withdrawn from the lagoon. Lagoons require only periodic cleanings when the settled solids significantly reduce lagoon volume. Since operation requires no sludge recycle, the hydraulic detention time is equal to the sludge retention time. Contaminant reduction in a lagoon system is typically less than other biological treatment systems. As a result, aerobic lagoons are commonly used together with other physical/chemical treatment processes, such as lime addition and settling, to ensure sufficient pollutant removal efficiencies.

Anaerobic lagoons are relatively deep ponds (up to 6 meters) with steep sidewalls in which anaerobic conditions are maintained by keeping organic loading so high that complete deoxygenation is prevalent. Some oxygenation is possible in a shallow surface zone. If floating materials in the waste form an impervious surface layer, complete anaerobic conditions will develop. Treatment or stabilization results from anaerobic digestion of organic wastes by acid-forming bacteria that break down organics. The resultant acids are then converted to carbon dioxide, methane, and other end products. Anaerobic lagoons are capable of providing treatment of high-strength wastewater and are resistant to shock loads.

In the typical anaerobic lagoon, raw wastewater enters near the bottom of the pond (often at the center) and mixes with the active microbial mass in the sludge blanket, which can be as much as 2 meters (6 feet)

deep. The discharge is located near one of the sides of the pond, submerged below the liquid surface. Excess sludge is washed out with the effluent and recirculation of waste sludge is not required.

Anaerobic lagoons are customarily contained within earthen dikes. Depending on soil and wastewater characteristics, lining with various impervious materials, such as rubber, plastic, or clay may be necessary. Pond geometry may vary, but surface area-to-volume ratios are minimized to enhance heat retention.

Waste stabilization in a facultative lagoon treatment system is accomplished by a combination of anaerobic microorganisms, aerobic microorganisms, and a preponderance of facultative microorganisms that thrive under anaerobic as well as aerobic conditions. Facultative systems consist of lagoons of intermediate depth (3 to 8 feet) in which the wastewater is stratified into three zones (see Figure 8-15). These zones consist of an anaerobic bottom layer, an aerobic surface layer, and an intermediate zone dominated by the facultative microorganisms. Stratification is a result of solids settling and temperature-water density variations. Oxygen in the surface zone is provided by natural oxygen transfer and photosynthesis or, as in the case of an aerated facultative lagoon, by mechanical aerators or diffusers. Facultative lagoons usually consist of earthen dikes, but some are lined with various impervious materials, such as synthetic geomembranes or clay.

A facultative lagoon is designed to permit the accumulation of settleable solids on the basin bottom. This sludge at the bottom of the facultative lagoon will undergo anaerobic digestion, producing carbon dioxide and methane. The liquid and gaseous intermediate products from the accumulated solids, together with the dissolved solids furnished in the influent, provide the food for the aerobic and facultative bacteria in the upper layers of the liquid in the lagoon. Recommended hydraulic detention time for a facultative lagoon without aeration is 7 to 30 days, with an organic loading of 15 to 50 pounds of BOD_5 per day per acre (see reference 7).

8.1.3.2   Anaerobic Systems

Types of anaerobic biological treatment systems include complex mix anaerobic digestors (see Figure 8-16), contact reactors with sludge recycle, and anaerobic filters. A digestor uses an air tight reactor where wastes are mixed with digestor contents that contain the suspended anaerobic microorganisms. A digestor operated in a complete mix mode without sludge recycling has a hydraulic detention time equal to the solids retention time. Anaerobic digestion in a reactor can also occur with sludge recycling. This permits a much larger solids retention time (SRT) than the hydraulic detention time. System stability is greater at increased SRTs, and since the hydraulic detention time can be decreased, the reactor volume can also be reduced. The anaerobic filter or biotower microbes are maintained in a film on packed solid media within an air-tight column. A variation of the anaerobic fixed-film process is a fluidized bed process. The basic tower design is similar to that of an aerobic reactor in that the influent is fed into the reactor at countercurrent flow. This process provides for very high SRTs and variable hydraulic detention times.

Stabilization of leachate in an anaerobic treatment unit requires the maintenance of a viable community of anaerobic microbes. Treatment efficiency is dependent on many interrelated factors such as hydraulic detention time, SRT, temperature, and, to a lesser extent, organic loading, nutrients, and toxics. Microorganisms responsible for degrading the organic waste must remain in the reactor long enough to reproduce. When the microbes spend less time in the system than they require to reproduce, the solids are eventually washed out of the system. Anaerobic treatment facilities are typically designed with an SRT of 2 to 10 times the washout time (typical washout time reported for organic acids is about 3.5 days). For degradation of organic acids in leachate, this washout time would yield an SRT of 7 to 35 days (see reference 7). The most common temperature regime for an anaerobic reactor is in the range of 25 to 38 degrees C (see reference 7). Typical loadings for anaerobic systems are from 30 to 100 pounds of COD per 1,000 cubic feet of reactor volume (see reference 7). Since the synthesis of new cellular material is slow in anaerobic systems, nutrient requirements are not as large as in aerobic systems. Nutrient addition needs to be evaluated and, in the case of leachate with low phosphorus concentrations, will require phosphorus addition.

8.1.3.3   Attached-Growth Biological Treatment Systems

Attached-growth biological treatment systems are used to biodegrade the organic components of a wastewater. In these systems, the biomass adheres to the surfaces of rigid supporting media. As wastewater contacts the supporting medium, a thin-film biological slime develops and coats the surfaces. As this film (consisting primarily of bacteria, protozoa, and fungi) grows, the slime periodically breaks off the medium and is replaced by new growth. This phenomenon of losing the slime layer is called sloughing and is primarily a function of organic and hydraulic loadings on the system. The effluent from the system is usually discharged to a clarifier to settle and remove the agglomerated solids.

Attached-growth biological systems are applicable to industrial wastewater amenable to aerobic biological treatment in conjunction with suitable pre- and post-treatment units. These systems are effective for the removal of suspended or colloidal materials.

The three major types of attached-growth systems used at landfills facilities are rotating biological contactors, trickling filters, and fluidized-bed biological reactors. These processes are described below.

Rotating biological contactors are a form of aerobic attached-growth biological treatment system where the biomass adheres to the surface of a rigid media. In a rotating biological contactor, the rigid media usually consists of a plastic disk or corrugated plastic medium mounted on a horizontal shaft (see Figure 8-17). The medium slowly rotates in wastewater (with 40 to 50 percent of its surface immersed) as the wastewater flows past. During the rotation, the medium picks up a thin layer of wastewater, which flows over its surface absorbing oxygen from the air. The biological mass growing on the medium surface absorbs organic pollutants, which then are biodegraded. Excess microorganisms and other solids are continuously removed from the film on the disk by shearing forces created by the rotation of the disk in the wastewater. The sloughed solids are carried with the effluent to a clarifier, where they are separated from the treated effluent.

Rotating biological contactors provide a greater degree of flexibility for landfills with changing leachate characteristics. Modular construction of rotating biological contactors permit their multiple staging to meet increases or decreases in treatment demand. Staging, which employs a number of rotating biological contactors operated in series, enhances biological treatment efficiency, improves shock-handling ability, and also may aid in achieving nitrification.

Typical rotating biological contactor design parameters include a hydraulic loading of 2.0 to 4.0 gallons per square feet per day and an organic loading of 2.0 to 3.5 pounds BOD_5 per 1,000 square feet per day (see reference 12).

Factors which affect the efficiency of rotating biological contactor systems include the type and concentration of organic matter, hydraulic detention time, rotational speed, media surface area submergence, and pre- and post-treatment activities. Variations of the basic rotating biological contactor process design include the addition of air to the tanks, chemicals for pH control, use of molded covers or housing for temperature control, and sludge recycle to enhance nitrification. Rotating biological contactors are typically well suited for the treatment of soluble organics and adequate for nitrification. They are low-rate systems capable of handling limited loadings capacity and are not efficient for degrading refractory compounds or removing metals (see reference 7).

Trickling filtration is another aerobic fixed-film biological treatment process that consists of a suitable structure, packed with inert medium, such as rock, wood, or plastic. The wastewater is distributed over the upper surface of the medium by either a fixed spray nozzle system or a rotating distribution system (see Figure 8-18). The inert medium develops a biological slime that absorbs and biodegrades organic pollutants. Air flows through the filter by convection, thereby providing the oxygen needed to maintain aerobic conditions.

Trickling filters are classified as low-rate or high-rate, depending on the organic loading. Typical design organic loading values range from 5 to 25 pounds and 25 to 45 pounds BOD_5 per 1,000 cubic feet per day for low-rate and high-rate, respectively (see reference 11). A low-rate filter generally has a media bed depth of 1.5 to 3 meters and does not use recirculation. A high-rate filter can have a bed depth from 1 to 9 meters and recirculates a portion of the effluent for further treatment (see reference 7).

A variation of a trickling filtration process is the aerobic biotower which can be operated in a continuous or semi-continuous manner. Influent is pumped to the top of a tower, where it flows by gravity through the tower. The tower is packed with media, plastic or redwood, containing the microbial growth. Biological degradation occurs as the wastewater passes over the media. Treated wastewater collects into the bottom of the tower. If needed, additional oxygen is provided via air blowers countercurrent to the wastewater flow. Alternative variations of this treatment process involve the inoculation of the raw influent with bacteria, adding nutrients, and using upflow biotowers. Wastewater collected in the biotowers is delivered to a clarifier to separate the biological solids from the treated effluent.

An aerobic fluidized-bed biological reactor is a variation of a fixed-film biological treatment process. Microorganisms are grown on either granular activated carbon or sand media. Influent wastewater enters the reactor through a distributor which is designed to provide for fluidization of the media (see Figure 8-19). As the biofilm grows, the media bed expands, thereby reducing the density of the media. The rising bed is intercepted at a given height with the bulk of the biomass removed from the media. The media then is returned to the reactor. Additional oxygen can be predissolved in the influent to enhance performance. The use of granular activated carbon as a medium integrates biological treatment and carbon adsorption processes, which has the advantage of handling loading fluctuations, as well as greater removals of organic contaminants.

Due to a short hydraulic detention time, this process is favorable for low to moderate levels of contamination. The vertical installation of the reactor and high loading capability reduces conventional land

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requirements. The maximum design loading is 400 pounds of BOD per 1,000 square feet of reactor area per day with a minimum hydraulic detention time of 5 to 10 minutes (see reference 7).

8.1.3.4   Activated Sludge

The activated sludge process is a specific continuous-flow, aerobic biological treatment process that employs suspended-growth aerobic microorganisms to biodegrade organic contaminants. In this process (shown in Figure 8-20), a suspension of aerobic microorganisms is maintained in a relatively homogeneous state by mechanical mixing or turbulence induced by diffused aerators in an aeration basin. This suspension of microorganisms is called the mixed liquor.

Wastewater is introduced into the basin and mixed with the tank contents. The biological process often is preceded by gravity settling to remove larger and heavier suspended solids. A series of biochemical reactions take place in the aeration tank. These reactions degrade organics and generate new biomass. Microorganisms oxidize the soluble and suspended organic pollutants to carbon dioxide and water using the available supplied oxygen. These organisms also agglomerate colloidal and particulate solids. After a specific contact period in the aeration basin, the mixture is passed to a settling tank where the microorganisms are separated from the treated water. A portion of the settled solids in the clarifier is recycled back to the aeration system to maintain the desired concentration of microorganisms in the reactor. The remainder of the settled solids is wasted and sent to sludge handling facilities.

To ensure biological stabilization of organic compounds in activated sludge systems, adequate nutrient levels must be available to the biomass. The primary nutrients are nitrogen and phosphorus. Lack of these nutrients can impair biological activity and result in reduced removal efficiencies. Certain leachates can have low concentrations of nitrogen and phosphorus relative to the oxygen demand. As a result, nutrient supplements (e.g., phosphoric acid addition for additional phosphorus) have been used in activated sludge systems at landfill facilities.

The effectiveness of the activated sludge process is governed by several design and operation variables. The key variables are organic loading, sludge retention time, hydraulic or aeration detention time, oxygen requirements, and the biokinetic rate constant (K). The organic loading is described as the food-to-microorganism (F/M) ratio, or kilograms of BOD_5 applied daily to the system per kilogram of mixed liquor suspended solids (MLSS). The MLSS in the aeration tank is determined by the rate and concentration of activated sludge returned to the tank. The organic loading (F/M ratio) affects the BOD_5 removal, oxygen requirements, biomass production, and the settleability of the biomass. The sludge (or solids) retention time (SRT) or sludge age is a measure of the average retention time of solids in the activated sludge system. Sludge retention time is important in the operating of an activated sludge system because it must be maintained at a level that is greater than the maximum generation time of microorganisms in the system. If adequate sludge retention time is not maintained, the bacteria are washed from the system faster than they can reproduce and the process fails. The SRT also affects the degree of treatment and production of waste sludge. A high SRT results in carrying a high quantity of solids in the system, obtaining a higher degree of treatment, and producing less waste sludge. The hydraulic detention time is used to determine the size of the aeration tank and should be determined by use of F/M ratio, SRT, and MLSS. The biokinetic rate constant (or K-rate) determines the speed of the biochemical oxygen demand reaction and generally ranges from 0.1 to 0.5 days^{-1} for municipal wastewater (see reference 11). The value of K for any given organic compound is temperature-dependent. Because microorganisms are more active at higher temperatures, the value of K increases with increasing temperature. Oxygen requirements are based on the amount of oxygen required for BOD_5 synthesis and the amount required for endogenous respiration. The design parameters will also vary with the type of wastewater to be treated. The oxygen requirement to satisfy BOD_5 synthesis is established by the characteristics of the wastewater. The oxygen requirement to satisfy endogenous respiration is determined by the total solids maintained in the system and their characteristics.

Modifications of the activated sludge process are common, as the process is extremely versatile and can be adapted for a wide variety of organically contaminated wastewater. The typical modification may represent a variation in one or more of the key design parameters, including the F/M loading, aeration

location and type, sludge return, and contact basin configuration. The modifications in practice have been identified by the major characteristics that distinguish the particular configuration. The characteristic types and modifications are briefly described as follows:

C   Conventional. The aeration tanks are long and narrow, with plug flow (i.e., little forward or backwards mixing).

C   Complete Mix. The aeration tanks are shorter and wider, and the aerators, diffusers, and entry points of the influent and return sludge are arranged so that the wastewater mixes completely.

C   Tapered Aeration. A modification of the conventional process in which the diffusers are arranged to supply more air to the influent end of the tank, where the oxygen demand is highest.

C   Step Aeration. A modification of the conventional process in which the wastewater is introduced to the aeration tank at several points, lowering the peak oxygen demand.

C   High Rate Activated Sludge. A modification of conventional or tapered aeration in which the aeration times are shorter, the pollutants loadings are higher per unit mass of microorganisms in the tank. The rate of BOD_5 removal for this process is higher than that of conventional activated sludge processes, but the total BOD_5 removals are lower.

C   Pure Oxygen. An activated sludge variation in which pure oxygen instead of air is added to the aeration tanks. The tanks are covered, and the oxygen-containing off-gas is recycled. Compared to normal air aeration, pure oxygen aeration requires a smaller aeration tank volume and treats high-strength wastewater and widely fluctuating organic loadings more efficiently.

C   Extended Aeration. A variation of complete mix in which low organic loadings and long aeration times permit more complete wastewater degradation and partial aerobic digestion of the microorganisms.

C   Contact Stabilization. An activated sludge modification using two aeration stages. In the first stage, wastewater is aerated with the return sludge in the contact tank for 30 to 90 minutes, allowing finely suspended colloidal and dissolved organics to absorb to the activated sludge. The solids are settled out in a clarifier and then aerated in the sludge aeration (stabilization) tank for 3 to 6 hours before flowing into the first aeration tank (see reference 11).

C   Oxidation Ditch Activated Sludge. An extended aeration process in which aeration and mixing are provided by brush rotors placed across a race-track-shaped basin. Waste enters the ditch at one end, is aerated by the rotors, and circulates.

Activated sludge systems are effective in the removal of soluble (dissolved) organics by biosorption as well as suspended and colloidal matter typically found in landfill leachate. Suspended matter is removed by entrapment in the biological floc while colloidal matter is removed by physiochemical adsorption to the biological floc. For example, inorganic contaminants, such as heavy metals, that are common in low concentrations in landfill wastewater are often precipitated and concentrated in the biological sludges generated from activated sludge systems at landfill facilities. Halogenated organic compounds may be driven off to a certain extent in the aeration process while other less volatile compounds are removed by a combination of biodegradation and air stripping in the aeration basin. Finally, activated sludge systems treating landfill leachates with an excess loading of certain nutrients (i.e. amounts of nitrogen that exceed the requirements of the biomass in the activated sludge system) can be operated so that nitrification of ammonia can occur in the activated sludge system. For higher concentrations, stand-alone nitrification systems may be required; these systems are discussed later in this chapter.

Conventional, plug-flow activated sludge systems can adequately treat the organic loadings found in low- to medium-strength landfill leachates. Higher-strength leachates often are treated at landfill facilities using extended aeration mode of activated sludge treatment. This process allows for a large hydraulic detention time of up to 29 hours and for a sludge detention time of 20 to 30 days (see reference 7). Aerator loading for the complete-mix extended-aeration process is between 10 to 15 pounds of BOD_5 per 1,000 cubic feet of aerator tank volume (see reference 7). Extended aeration also provides for minimal operator supervision in comparison to other activated sludge processes and occasional sludge wasting. EPA sampled a facility (EPA sampling episode 4759) in the Hazardous subcategory that employed a complete-mix extended-aeration treatment process for high-strength leachate. Design parameters for this system include influent BOD_5 loading of 3520 mg/L with a hydraulic detention time of 28 hours. Higher-strength leachates are also occasionally treated with a combination of biological processes, sometimes using a lagoon or attached growth system prior to the activated sludge system to reduce organic loading. Since activated sludge systems are sensitive to the loading and flow variations typically found at landfill facilities, equalization is often required prior to treatment using activated sludge systems. Also, activated sludge

systems treating landfill leachates typically generate excess amounts of secondary sludge that may require additional stabilization, dewatering, and disposal.

8.1.3.5   Powdered Activated Carbon Biological Treatment

In this biophysical treatment process, powdered activated carbon is added to a biological treatment system (usually an activated sludge system). The adsorbent qualities of the powdered carbon aid in the removal of organic compounds, particularly those that may be difficult to biodegrade. Powdered activated carbon also enhances color removal and the settling characteristics of the biological floc.

The mixture of influent, activated sludge biomass, and powdered activated carbon is held in the aeration basin for a sufficient detention time adequate for the desired treatment efficiencies (see Figure 8-21). After contact in the aeration basin, the mixture flows to a clarifier, where settled solids are fed back to the aeration basin to maintain adequate concentrations of microorganisms and carbon. Clear overflow from the clarifiers is either further processed or discharged. Fresh carbon is periodically added to the aeration basin as required and is dependent on desired removal efficiencies. Excess solids are removed directly from the recycled sludge stream. Wasted solids can be processed by conventional dewatering means or by wet-air oxidation for the destruction of organics and regeneration of activated carbon. Regeneration also can be handled off site for smaller applications.

Powdered activated carbon activated sludge treatment combines physical adsorption properties of carbon with biological treatment, achieving a higher degree of treatment than possible by either mode alone. Powdered activated carbon removes the more difficult to degrade refractory organics, enhances solids removal, and buffers the system against loading fluctuations and shock loads. Variations of the powdered activated carbon biological process includes operation in a batch fill and draw mode (similar to a sequencing batch reactor), multiple-stage powdered activated carbon units, and combinations of aerobic and anaerobic powdered activated carbon biological systems. Operation in a batch mode provides for flexibility in the system, by readily allowing for adjustments to the time and aeration mode in each process

stage. This mode of operation is particularly applicable to the treatment of leachate with variable composition and strength. The powdered activated carbon biological treatment process is well suited for the treatment of leachate containing high concentrations of soluble organics (particularly with low BOD_5 to COD ratios). It can obtain better color and refractive organics removal than conventional biological processes and can provide for treatment of leachates contaminated with various trace organic compounds.

8.1.3.6 Sequencing Batch Reactors (SBRs)

A sequencing batch reactor is a suspended-growth biological system in which the wastewater is mixed with existing biological floc in an aeration basin. SBRs are unique in that a single tank acts as an equalization tank, an aeration tank, and a clarifier (see Figure 8-22). A SBR is operated on a batch basis where the wastewater is mixed and aerated with the biological floc for a specific period of time. The contents of the basin then are allowed to settle and the liquid (or supernatant) is decanted. The batch operation of a sequencing batch reactor makes it applicable to wastewater that is highly variable because each batch can be treated differently, depending on its waste characteristics.

A sequencing batch reactor system has four cycles: fill, react, settle, and decant. The fill cycle has three phases. The first phase, called static fill, introduces the wastewater to the system under static conditions. During this phase, anaerobic conditions can exist. During the second phase, the wastewater is mixed to eliminate the scum layer and to initiate the oxygenation process. The third phase consists of aeration and biological degradation. The react cycle is a time-dependent process that continually mixes and aerates the wastewater while allowing the biological degradation process to complete. Because the reaction is a batch process, the period of time of aeration can vary to match the characteristics and loadings of the wastewater. The settling cycle utilizes a large surface area (entire reactor area) and a lower settling rate than used in conventional sedimentation processes, to allow for settling under quiescent conditions. Next, during the decant cycle, approximately one-third of the tank volume is removed by subsurface withdrawal. This treated effluent then can be further treated or disposed. The period of time that the reactor waits prior to the commencement of another batch processing is the idle period. Excess biomass is periodically removed

from the sequencing batch reactor when the quantity exceeds that needed for operation and is usually dewatered prior to disposal.

A sequencing batch reactor carries out all of the functions of a conventional continuous-flow activated sludge process, such as equalization, biological treatment, and sedimentation, in a time sequence rather than a space sequence. Detention times and loadings vary with each batch and are highly dependent on the loadings in the raw wastewater at that time. Typically, a sequencing batch reactor operates with a hydraulic detention time of 1 to 10 days with an SRT of 10 to 30 days. The MLSS is maintained at 3,500 to 10,000 mg/L (see reference 7). The overall control of the system can be accomplished automatically by using level sensors or timing devices. By using a single tank to perform all of the required functions associated with biological treatment, a sequencing batch reactor saves on land requirements. It also provides for greater operation flexibility for treating leachate with viable waste characteristics by being able to readily vary detention time and mode of aeration in each stage. Sequencing batch reactors also can be used to achieve complete nitrification/denitrification and phosphorus removal.

8.1.3.7 Nitrification Systems

In this process, nitrifying bacteria are used in an aerobic biological treatment system to convert ammonia compounds to nitrate compounds. Nitrification is usually followed by denitrification (see next section) which converts nitrates to nitrogen gas. Nitrifying bacteria, such as *nitrosomonas* and *nitrobacter*, derive their energy for growth from the oxidation of inorganic nitrogen compounds. *Nitrosomonas* converts ammonia to nitrites, and *nitrobacter* converts nitrites to nitrates.

The nitrification process usually follows a standard biological process that has already greatly reduced the organic content of the wastewater; however, there are some biological systems that can provide organic (BOD_5) removal concurrently with ammonia destruction. The nitrification process can be oriented as either a suspended growth process (e.g. activated sludge system) or an attached-growth process (e.g. trickling filter).

8.1.3.8 Denitrification Systems

Denitrification is an anoxic process whereby nitrate nitrogen is converted to gaseous nitrogen, and possibly nitrous oxide and nitric oxide. Denitrification is a two step process in which the first step converts nitrates to nitrites, and the second step converts nitrite to nitrogen gas. The bacteria use nitrogen as an electron source rather than oxygen in digesting a carbon food source. Since the waste stream reaching the denitrification process has low levels of organic material, a carbon source (usually methanol) must be added.

The denitrification process can occur as a suspended-growth process or as an attached-growth process. Attached growth systems can be designed as either fixed-bed or fluidized-bed reactor systems. Effluents from denitrification processes may need to be re-aerated to meet dissolved oxygen discharge requirements.

8.1.3.9 Wetlands Treatment

An alternative and innovative biological treatment technology for treating landfill wastewater is wetland treatment. Wetlands can either be natural or man-made (artificial) systems and contain vegetation that allow for the natural attenuation of contaminants. Wetlands are designed to provide for a contact time of usually 10 to 30 days. Vegetation in the wetlands transforms nutrients and naturally degrades organics. Certain metals also can be absorbed by vegetation through root systems. Key design variables include loading rates, climatic constraints, and site characteristics. Wetland systems are still mainly experimental and are not a widely accepted or proven treatment technology for the treatment of landfill leachate.

8.1.4 Sludge Handling

Sludges are generated by a number of treatment technologies, including equalization, gravity-assisted separation, chemical precipitation, and biological treatment. These sludges are further processed at landfill sites using various methods. The following sections describe each type of sludge-handling system used within the Landfills industry.

8.1.4.1   Sludge Slurrying

Sludge slurrying is the process of transporting sludge from one treatment process to another. It only can be applied to liquid sludges that can be pumped through a pipe under pressure. National estimates based on EPA's Detailed Questionnaire data indicate that 33 percent of indirect hazardous landfills and less than one percent of indirect non-hazardous landfills use sludge-slurrying systems as part of their wastewater treatment systems.

8.1.4.2   Gravity Thickening

Gravity thickening, as shown in Figure 8-23, consists of placing the sludge in a unit similar to a gravity-assisted separator, where the sludge is allowed to settle, with the liquid supernatant remaining at the top. The thickened sludge is then removed, and the separated liquid is returned to the wastewater treatment system for further treatment. Usually sludges that contain two to three percent solids can be thickened to approximately five to ten percent solids using gravity thickening. National estimates based on the Detailed Questionnaire responses show that 67 percent of indirect hazardous landfills, 4 percent of indirect non-hazardous landfills, and 7 percent of direct non-hazardous landfill facilities employ gravity thickening as part of their wastewater treatment systems.

8.1.4.3   Pressure Filtration

Plate-and-frame pressure-filtration systems are used at landfill facilities to dewater sludges from physical/chemical and biological treatment processes. Sludges generated at a total solids concentration of two to five percent by weight are dewatered to a 30 to 50 percent solids mass using plate-and-frame filtration (see reference 3). Sludges from treatment systems can be thickened by gravity or stabilized prior to dewatering by pressure filtration or may be processed directly with the plate-and-frame filtration unit.

A pressure filter consists of a series of screens (see Figure 8-24) upon which the sludge is applied under pressure. A precoat material may be applied to the screens to aid in solids removal. The applied pressure

forces the liquid through the screen, leaving the solids to accumulate behind the screen. Filtrate which passes through the screen media is recirculated back to the head of the on-site wastewater treatment plant. Screens (also referred to as plates) are held by frames placed side-by-side and held together with a vice-type mechanism. The unit processes sludge until all of the plates are filled with dry sludge as indicated by a marked rise in the application pressure. Afterwards, the vice holding the plates is loosened and the frames separated. Dried sludge is manually scraped from the plates and collected in a hopper for final disposal. The size of the filter and the number of plates utilized depends not only on the amount of solids produced by treatment processes, but also is highly dependent on the desired operational requirements for the filter. A plate-and-frame filter can produce a drier sludge than possible with most other methods of sludge dewatering. It is usually not operated continuously, but offers operational flexibility since it can be operated in a batch mode.

Pressure filtration is the most common method of sludge dewatering used at landfill facilities. National estimates indicate that 67 percent of indirect hazardous landfills, 5 percent of indirect non-hazardous landfills, and 8 percent of direct non-hazardous landfill facilities use pressure filtration systems as part of their wastewater treatment systems.

8.1.4.4   Sludge Drying Beds

Sludge-drying beds are an economical and effective means of dewatering sludge when land is available. Sludge may be conditioned by thickening or stabilization prior to application on the drying beds, which are typically made up of sand and gravel. Sludge is placed on the beds in an 8 to 12 inch layer and allowed to dry. The drying area is partitioned into individual beds, approximately 20 feet wide by 20 to 100 foot long (see reference 13), or a convenient size so that one or two beds will be filled by the sludge discharge from other sludge-handling units or sludge- storage facilities. The outer boundaries may be constructed with concrete or earthen embankments for open beds. Open beds are used where adequate area is available and sufficiently isolated to avoid complaints caused by odors. Covered beds with greenhouse-

type enclosures are used when it is necessary to dewater sludge continuously throughout the year, regardless of the weather, and where sufficient isolation does not exist for the installation of open beds.

Sludge is dried by drainage through the sludge mass and supporting sand and by evaporation from the surface exposed to the air. Most of the water leaves the sludge by drainage; thus, the provision of an adequate underdrainage system is essential. Drying beds are equipped with lateral drainage tiles that should be adequately supported and covered with coarse gravel or crushed stone. The sand layer should be from 9 to 12 inches deep (see reference 13) with an allowance for some loss from cleaning operations. Water drained from the sludge is collected and typically recirculated back to the on-site wastewater treatment system. Sludge can be removed from the drying bed after it has drained and dried sufficiently. The moisture content is approximately 60 percent after 10 to 15 days under favorable conditions (see reference 13). Dried sludge is manually removed from the beds and sent for on-site or off-site disposal. Figure 8-25 depicts the cross section of a typical drying bed.

8.1.5   Zero Discharge Treatment Options

In this section, additional treatment processes and disposal methods associated with zero or alternative discharge at landfill facilities are described. Based on the responses to the Detailed Questionnaire, national estimates indicate that 27 percent of all non-hazardous landfill facilities and 96 percent of all hazardous landfill facilities use zero-discharge treatment options. The most commonly used zero-discharge treatment method employed by these facilities is land application and recirculation. This section describes land application, recirculation, deep-well disposal, evaporation, solidification, and off-site disposal.

Land application involves the spreading of the wastewater over an area of land that is capped, closed, or an unused portion of a landfill. The land generally has sufficient percolation characteristics to allow the water to drain adequately into the soil. The area is assessed to insure that the soil can provide adequate biological activity to cause the degradation of organic pollutants and also to provide sufficient binding of any metals present.

Recirculation involves the spraying of recycled landfill leachate over areas of a landfill. Although this process promotes biodegradation and evaporation of the leachate volume, recirculation is primarily used as a means of dust control.

Deep well disposal consists of pumping the wastewater into a disposal well, which then discharges the liquid into a deep aquifer. Normally, these aquifers are thoroughly characterized to insure that they are not hydrogeologically connected to a drinking-water supply. The characterization requires the confirmation of the existence of impervious layers of rock above and below the aquifer.

Traditionally used as a method of sludge dewatering, evaporation, or solar evaporation, can also involve the discharge and ultimate storage of wastewater into a shallow, lined, on-site ditch. Since the system is open to the atmosphere, the degree of evaporation is greatly dependent upon climatic conditions.

Solidification is a process in which materials, such as fly ash, cements, and lime, are added to the waste to produce a solid. Depending on both the contaminant and binding material, the solidified waste may be disposed of in a landfill.

Some facilities that have a low leachate generation rate (either because of arid conditions or capping), transport their wastewater off site to either another landfill facility's wastewater treatment system or to a Centralized Wastewater Treatment (CWT) facility for ultimate disposal.

8.2   Treatment Performance and Development of Regulatory Options

This section presents an evaluation of performance data on treatment systems collected by EPA during field sampling programs. The results of these EPA sampling episodes assisted the Agency in evaluating the various types of treatment technologies. For those facilities employing the selected technologies, the sampling data were used to develop the effluent limitations. A more detailed discussion of the development of effluent limitations can be found in Chapter 11.

8.2.1 Performance of EPA Sampled Treatment Processes

To collect data on potential BAT treatment technologies, EPA reviewed responses to the Detailed Questionnaire to identify candidate facilities that had well-operated and designed wastewater treatment systems. EPA conducted 19 site visits to 18 facilities to evaluate treatment systems. Based on these site visits, EPA selected a total of six facilities for sampling which consisted of five consecutive days of sampling raw influent wastewater and intermediate and effluent points in the wastewater treatment system. EPA conducted one of these 5-day sampling episodes (4690) at a facility that was eventually excluded from the regulation because it is a captive landfill. In addition, the only technology sampled at this facility primarily treated contaminated ground water. For the reasons discussed in Chapter 2, EPA decided to exclude contaminated ground water flows from this regulation. EPA did not use the data collected during this sampling episode in selection of pollutants of interest or in the calculation of effluent limitations. Therefore, EPA does not discuss this facility further in this section. For the remaining five sampling facilities, EPA collected data on a variety of biological and chemical treatment processes. Technologies evaluated at the selected sampling facilities include hydroxide precipitation, activated sludge, sequencing batch reactors, multimedia filtration, and reverse osmosis. Table 4-2 in Chapter 4, presents a summary of the treatment technologies sampled during each EPA sampling episode. Presented below are the summaries of the treatment system performance data for each of the sampling episodes that EPA evaluated in the development of the effluent limitations guidelines and standards.

8.2.1.1 Treatment Performance for Episode 4626

EPA performed a 5-day sampling program during episode 4626 to obtain performance data on several treatment technologies including hydroxide precipitation, biological treatment using anaerobic and aerobic biotowers, and multimedia filtration. A flow diagram of the landfill wastewater treatment system sampled during episode 4626 is presented in Figure 8-26. The wastewater treatment system used at this Subtitle D municipal facility treats predominately landfill generated wastewater, including leachate and gas condensate. Table 8-2 presents a summary of percent removal data collected at episode 4626 for the performance of the biological treatment system and for the entire treatment system, excluding the multimedia

filtration system used to polish the discharge from the effluent holding tank. EPA calculated percent removal efficiencies for the processes by first obtaining an average concentration based upon the daily sampling results for each sample collection location (influent and effluent point to the treatment process). EPA calculated the percent removal efficiency of the system using the following equation:

$$\text{Percent Removal} = \frac{[\text{Influent Concentration - Effluent Concentration}]}{\text{Influent Concentration}} \times 100$$

EPA reported negative and zero percent removals for a treatment process on the table as 0.0 percent.

EPA determined the treatment efficiency of the biological treatment unit operation using the data obtained from sampling points 04 and 07 (see Figure 8-26). As demonstrated on the Table 8-2, the biological treatment unit experienced good overall removals for TOC (93.0 percent), COD (90.85 percent), and ammonia as nitrogen (99.14 percent). The biological unit operation alone did not demonstrate high removals for BOD_5 (10.2 percent), TSS (9.32 percent), or for various metals (generally less than 10 percent removals) because the pollutants were generally not present in the biological treatment unit influent at treatable levels. The unit's influent BOD_5 was 39.2 mg/L, TSS was 11.8 mg/L, and most metals were not at detectable levels even though the raw wastewater at this facility exhibited a BOD_5 concentration of 991 mg/L, TSS of 532 mg/L, and several metals at treatable levels. The biological treatment unit influent was low because this facility employed large aerated equalization tanks and a chemical precipitation system prior to biological treatment. The equalization tanks had a retention time of approximately 15 days and were followed by a chemical precipitation system using sodium hydroxide. Due to the long retention time and wastewater aeration, significant biological activity occurred in these tanks. The resulting insoluble pollutants were removed in the primary clarifier prior to entering the biological towers. EPA did not detect organic pollutant parameters in the effluent from the biological treatment process with the exception of 1,4-dioxane at a concentration of 13.8 ug/L.

To determine the treatment efficiency of the entire treatment system, EPA determined the influent concentration by taking a flow-weighted average of the two influent sampling points, sampling points 01 and 02. EPA represented the effluent from the treatment system by sample point 07. The entire treatment system experienced good removals for the following conventional and nonconventional pollutants parameters: BOD_5, TSS, ammonia as nitrogen, COD, TOC, and total phenols. Each of the organic pollutant parameters identified in the influent to the treatment system was removed to non-detectable levels, with the exception of 1,4-dioxane, which still experienced a high percent removal (94.2 percent). Most metals had good percent removals or were removed to non-detectable levels.

8.2.1.2   Treatment Performance for Episode 4667

EPA performed a 5-day sampling program during episode 4667 to obtain performance data on various treatment units, including ammonia removal, hydroxide precipitation, biological treatment using a sequencing batch reactor, granular activated-carbon adsorption, and multimedia filtration. A flow diagram of the landfill wastewater treatment system sampled during episode 4667 is presented in Figure 8-27. The wastewater treatment process used at this Subtitle D non-hazardous facility primarily treats landfill generated wastewater and a small amount of sanitary wastewater flow from the on-site maintenance facility. Table 8-3 presents a summary of percent removal data collected during episode 4667 for the biological treatment unit operation (SBR) and for the entire treatment system.

EPA determined the treatment efficiency of the biological treatment unit using the data obtained from sampling points 03 and 04 (see Figure 8-27). As demonstrated on Table 8-3, the SBR treatment unit experienced moderate overall removals for TOC (43.4 percent), COD (24.7 percent), and BOD_5 (48.7 percent). The Agency observed improved removal efficiencies for TSS (82.9 percent), total phenols (74.2 percent), and ammonia as nitrogen (80.7 percent). Metals, such as barium, chromium, and zinc, had low removal efficiencies. However, as also noted for facility 4626, the Agency observed these metals in the influent to the biological system at low concentrations, often close to the detection limit. Other metals also

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had poor removal efficiencies including boron and silicon. EPA did not detect organic parameters in the effluent from the SBR treatment unit.

EPA determined the treatment efficiency of the entire treatment system at the facility using the data obtained from sampling points 01 and 06 (see Figure 8-27). Overall the treatment system experienced good removals for BOD_5, TSS, ammonia as nitrogen, COD, TOC and total phenols. Each of the organic pollutants detected in the influent was removed to non-detect levels in the effluent. Also, each of the metal parameters experienced a good removal rate through the treatment system.

8.2.1.3 Treatment Performance for Episode 4721

EPA performed a 5-day sampling program during episode 4721 to obtain performance data on the sequencing batch reactor (SBR) treatment unit operation installed at this Subtitle C hazardous facility. A flow diagram of the landfill wastewater treatment system sampled during episode 4721 is presented in Figure 8-28. The wastewater treatment process used at this facility treats predominately landfill generated wastewater. The majority of the landfill wastewater was generated by Subtitle D non-hazardous landfills. However, the facility also commingled wastewater generated by an on-site hazardous waste landfill for treatment. The facility also treats limited amounts of off-site generated wastewater at the on-site treatment plant, primarily from another landfill facility operated by the same entity. Table 8-4 presents a summary of percent removal data collected during episode 4721 for the SBR treatment unit.

EPA determined the treatment efficiency of the biological treatment unit using the data obtained from sampling points 01 and 02 (see Figure 8-28). As demonstrated on the Table 8-4, the SBR treatment unit experienced good overall removals for a number of convention/nonconventional and organic parameters, including total phenols, BOD_5, aniline, benzoic acid, 2-propanone, 2-butanone, naphthalene, alpha terpineol, ethylbenzene, p-cresol, m-xylene, 4-methyl-2-pentanone, toluene, phenol, hexanoic acid, and ammonia as nitrogen. EPA observed removal of all of the organic parameters detected in the influent to non-detect levels in the effluent. COD and TOC percent removals were observed at 72.2 and 66.3

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percent, respectively. The percent removal for TSS was 72.1 percent. Metals with quantitative percent removals include arsenic (61.9 percent), chromium (46.3 percent), copper (61.2 percent), and zinc (66.3 percent).

8.2.1.4   Treatment Performance for Episode 4759

EPA performed a 5-day sampling program during episode 4759 to obtain performance data on various treatment processes installed at this Subtitle C hazardous facility, including chemical precipitation using ferric chloride and sodium hydroxide and biological treatment using an activated sludge process. A flow diagram of the landfill wastewater treatment system sampled during episode 4759 is presented in Figure 8-29. The wastewater treatment process used at this facility treats predominately landfill generated wastewater, but also handles limited amounts of contaminated storm water from storage containment systems. Table 8-5 presents a summary of percent removal data collected at episode 4759 for the biological treatment units only and for the entire treatment system (combined chemical precipitation and biological treatment processes).

EPA determined the treatment efficiency of the biological treatment unit operations using the data obtained from sampling points 02 and 03 (see Figure 8-29). As demonstrated on the Table 8-5, the biological treatment units experienced good overall removals for a number of conventional/nonconventional and organic parameters, including BOD_5, COD, TOC, total phenols, aniline, benzoic acid, 2,4-dimethylphenol, 2-propanone, methylene chloride, 2-butanone, benzyl alcohol, isobutyl alcohol, o-cresol, p-cresol, 4-methyl-2-pentanone, phenol, pyridine, toluene, and hexanoic acid. Most of the organic parameters detected in the influent were removed to non-detect levels in the effluent from the biological treatment units. Most of the metal parameters, such as chromium, copper, selenium, titanium, and zinc, were observed at low concentrations in the influent to the biological treatment units and, therefore, did not demonstrate good removal rates.

EPA determined the treatment efficiency of the entire treatment system at the facility using the data obtained from sampling points 01 and 03 (see Figure 8-29). As demonstrated on Table 8-5, the entire treatment system experienced good overall removals for a number of convention/nonconventional and organic parameters, including total phenols, BOD_5, 2,4-dimethylphenol, aniline, benzene, benzoic acid, 2-propanone, methylene chloride, 2-butanone, benzyl alcohol, isobutyl alcohol, o-cresol, p-cresol, 4-methyl-2-pentanone, phenol, pyridine, toluene, tripropyleneglycol methyl ether, and hexanoic acid. Most of the organic parameters detected in the influent were removed to non-detectable levels in the effluent. COD and TOC percent removals were observed at 76.4 percent and 84.2 percent, respectively. Ammonia as nitrogen and TSS had poor removal rates of 25.7 percent and 26.6 percent, respectively. Metals with quantitative percent removals include arsenic (46.6 percent), chromium (80.2 percent), copper (45.2 percent), strontium (66.8 percent), titanium (89.6 percent), and zinc (62.5 percent). Pesticide/herbicide parameters such as 2,4-DB, dicamba and dichloroprop had good removal efficiencies through the treatment system. Dioxin/furan parameters were not detected in either the influent or effluent samples.

8.2.1.5 Treatment Performance for Episode 4687

EPA performed a 5-day sampling program during episode 4687 to obtain performance data on the reverse osmosis treatment process installed at this Non-Hazardous Subtitle D facility. A flow diagram of the landfill wastewater treatment system sampled during episode 4687 is presented in Figure 8-30. The wastewater treatment process used at this facility treats on-site landfill generated wastewater. Table 8-6 presents a summary of percent removal data collected at episode 4687 for a single-pass reverse osmosis unit including the multimedia filtration unit and the entire treatment system consisting of a second pass reverse osmosis unit.

EPA determined the treatment efficiency of the single-pass reverse osmosis treatment system at the facility using the data obtained from sampling points 01 and 02 (see Figure 8-30). As demonstrated on Table 8-6, the single-pass reverse osmosis treatment system demonstrated good overall removals for a number of conventional/nonconventional and organic parameters, including TSS, TOC, BOD_5, TDS, COD, 4-methyl-

2-pentanone, alpha terpineol, benzoic acid, tripropyleneglycol methyl ether, and hexanoic acid. A number of other organic parameters also were observed to have been removed by the treatment process at various levels lower than 95 percent. Total phenols and ammonia as nitrogen percent removals were observed at 75.1 and 76.7 percent, respectively. Metals with quantitative percent removals include arsenic (87.4 percent), boron (54.1 percent), silicon (88.3 percent), and strontium (92.9 percent). All of the pesticide/herbicide parameters detected in the influent, including 2,4,5-TP, 2,4-D, 2,4-DB, dicamba, dichlorprop, MCPA and MCPP, were removed to non-detect levels.

EPA determined the treatment efficiency of the entire treatment system at the facility using the data obtained from sampling points 01 and 03 (see Figure 8-30). The additional polishing reverse osmosis unit caused the removal efficiency of most of the conventional and nonconventional parameters to increase. These parameters include BOD_5, ammonia as nitrogen, COD, TDS, TOC, and total phenols. The removal efficiency of several organic parameters were observed to increase from the single-pass treatment system including 2-butanone, 2-propanone, phenol, p-cresol, and toluene. The percent removal for boron also increased from 54.1 percent in the single-pass reverse osmosis system to 94.4 percent in the two-stage reverse osmosis treatment system.

Table 8-1: Wastewater Treatment Technologies Employed at In-Scope Landfill Facilities
(Percent of Landfills Industry)

Treatment Technology	Subtitle D Non-Hazardous		Subtitle C Hazardous
	Direct Discharge	Indirect Discharge	Indirect Discharge
Equalization	21.0	11.2	0.0
Neutralization	6.3	6.7	33.3
Chemical oxidation	11.2	0.5	33.3
Chemical precipitation	9.1	5.4	33.3
Adsorption	1.4	1.3	0.0
Filtration	10.5	1.5	0.0
Stripping	4.2	1.3	0.0
Biological treatment	32.2	3.8	66.7
Gravity assisted separation	27.3	9.0	66.7
Sludge preparation	3.5	0.5	33.3
Sludge dewatering	12.6	5.2	66.7

Table 8-2: Treatment Technology Performance for Facility 4626 - Subtitle D Municipal

Pollutant of Interest Subtitle D Municipal	CAS #	Biological Treatment Unit Operation Only: Sample Points 4 to 7						Entire Treatment System: Sample Points 1 & 2 (flow weighted) to 7					
		DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal	DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal
Conventional													
BOD	C-002	2,000	04	39,200	07	35,200	10.2	2,000	1+2	991,067	07	35,200	96.5
TSS	C-009	4,000	04	11,800	07	10,700	9.3	4,000	1+2	532,800	07	10,700	98.0
Nonconventional													
Ammonia as Nitrogen	7664417	10.0	04	135,000	07	1,156	99.1	10.0	1+2	193,333	07	1,156	99.4
COD	C-004	5,000	04	1,742,600	07	159,400	90.9	5,000	1+2	4,028,000	07	159,400	96.0
Hexavalent Chromium	18540299	10.0	04	ND	07	ND		10.0	1+2	68.7	07	ND	85.4
Nitrate/Nitrite	C-005	50.0	04	1,535	07	130,500	0.0	50.0	1+2	693	07	130,500	0.0
TDS	C-010		04	5,960,000	07	5,181,000	13.1		1+2	5,012,667	07	5,181,000	0.0
TOC	C-012	1,000	04	758,000	07	52,800	93.0	1,000	1+2	1,316,200	07	52,800	96.0
Total Phenols	C-020	50.0	04	182	07	50.0	72.5	50.0	1+2	1,204	07	50.0	95.9
Organics													
1,4-Dioxane	123911	10.0	04	NS	07	13.8	NS	10.0	1+2	240	07	13.8	94.2
2-Butanone	78933	50.0	04	NS	07	ND	NS	50.0	1+2	227,893	07	ND	100
2-Propanone	67641	50.0	04	NS	07	ND	NS	50.0	1+2	27,655	07	ND	99.8
4-Methyl-2-Pentanone	108101	50.0	04	NS	07	ND	NS	50.0	1+2	598	07	ND	91.6
Alpha Terpineol	98555	10.0	04	NS	07	ND	NS	10.0	1+2	134	07	ND	92.6
Benzoic Acid	65850	50.0	04	NS	07	ND	NS	50.0	1+2	14,657	07	ND	99.7
Hexanoic Acid	142621	10.0	04	NS	07	ND	NS	10.0	1+2	36,256	07	ND	100
Methylene Chloride	75092	10.0	04	NS	07	ND	NS	10.0	1+2	50.3	07	ND	80.1
N,N-Dimethylformamide	68122	10.0	04	NS	07	ND	NS	10.0	1+2	39.3	07	ND	74.5
O-Cresol	95487	10.0	04	NS	07	ND	NS	10.0	1+2	86.4	07	ND	88.4
P-Cresol	106445	10.0	04	NS	07	ND	NS	10.6 /10.0	1+2	ND	07	ND	
Phenol	108952	10.0	04	NS	07	ND	NS	10.0	1+2	685	07	ND	98.5
Toluene	108883	10.0	04	NS	07	ND	NS	10.0	1+2	1,095	07	ND	99.1
Tripropyleneglycol Methyl Ether	20324338	99.0	04	NS	07	ND	NS	105 /99.0	1+2	ND	07	ND	
Metals													
Barium	7440393	200	04	10.3	07	21.8	0.0	200	1+2	2427	07	21.8	99.1
Boron	7440428	100	04	3,211	07	2,925	8.9	100	1+2	4330	07	2,925	32.5
Chromium	7440473	10.9	04	11.6	07	ND	6.5	10.9	1+2	36.6	07	ND	70.3
Silicon	7440213	100	04	784	07	648	17.4	100	1+2	768	07	648	15.7
Strontium	7440246	80.3	04	ND	07	82.5	0.0	100	1+2	2,912	07	82.5	97.2
Titanium	7440326	4.2	04	4.2	07	ND	1.0	4.2	1+2	13.0	07	ND	67.9
Zinc	7440666	10.6	04	ND	07	12.0	0.0	20.0	1+2	144	07	12.0	91.6
Pesticides/Herbicides													
Dichloroprop	120365	1.0	04	NS	07	NS	NS	1.0	1+2	NS	07	NS	NS
Disulfoton	298044	2.0	04	NS	07	NS	NS	2.0	1+2	NS	07	NS	NS
Dioxins/Furans													
1234678-HpCDD	35822469	50.0 pg/L	04	NS	07	NS	NS	50.0 pg/L	1+2	NS	07	NS	NS
OCDD	3268879	100 pg/L	04	NS	07	NS	NS	100 pg/L	1+2	NS	07	NS	NS

Negative percent removal are recorded as 0.0.

NS: Not Sampled   SP: Sample point.

ND: Non-detect   DL: Specific detection limits of sample when there is a non-detect, otherwise it is the method detection limit

Table 8-3: Treatment Technology Performance for Facility 4667 - Subtitle D Municipal

Pollutant of Interest Subtitle D Municipal	CAS #	Biological Treatment Unit Operation Only: Sample Points 3 to 4						Entire Treatment System: Sample Points 1 to 6					
		DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal	DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal
Conventional													
BOD	C-002	2,000	03	232,600	04	119,300	48.7	2,000	01	1,088,000	06	201,000	81.5
TSS	C-009	4,000	03	59,600	04	10,200	82.9	4,000	01	93,400	06	ND	95.7
Nonconventional													
Ammonia as Nitrogen	7664417	10.0	03	134,800	04	26,040	80.7	10.0	01	295,900	06	12,060	95.9
COD	C-004	5,000	03	635,000	04	478,200	24.7	5,000	01	2,932,000	06	251,000	91.4
Hexavalent Chromium	18540299	10.0	03	ND	04	ND		10.0	01	26.0	06	ND	61.5
Nitrate/Nitrite	C-005	50.0	03	14,400	04	87,800	0.0	50.0	01	494	06	87,000	0.0
TDS	C-010		03	4,024,000	04	3,987,000	0.9		01	6,232,000	06	3,834,000	38.5
TOC	C-012	1,000	03	212,600	04	120,400	43.4	1,000	01	1,098,600	06	82,000	92.5
Total Phenols	C-020	50.0	03	204	04	52.6	74.2	50.0	01	940	06	ND	94.7
Organics													
1,4-Dioxane	123911	10.0	03	NS	04	ND	NS	10.0	01	323	06	ND	96.9
2-Butanone	78933	50.0	03	NS	04	ND	NS	50.0	01	8,767	06	ND	99.4
2-Propanone	67641	50.0	03	NS	04	ND	NS	50.0	01	13,021	06	ND	99.6
4-Methyl-2-Pentanone	108101	50.0	03	NS	04	ND	NS	50.0	01	1,239	06	ND	96.0
Alpha Terpineol	98555	10.0	03	NS	04	ND	NS	10.0	01	430	06	ND	97.7
Benzoic Acid	65850	50.0	03	NS	04	ND	NS	50.0	01	33,335	06	ND	99.9
Hexanoic Acid	142621	10.0	03	NS	04	ND	NS	10.0	01	37,256	06	ND	100
Methylene Chloride	75092	10.0	03	NS	04	ND	NS	208 /10.0	01	ND	06	ND	
N,N-Dimethylformamide	68122	10.0	03	NS	04	ND	NS	10.0	01	1,008	06	ND	99.0
O-Cresol	95487	10.0	03	NS	04	ND	NS	10.0	01	2,215	06	ND	99.6
P-Cresol	106445	10.0	03	NS	04	ND	NS	10.0	01	ND	06	ND	
Phenol	108952	10.0	03	NS	04	ND	NS	10.0	01	387	06	ND	97.4
Toluene	108883	10.0	03	NS	04	ND	NS	10.0	01	668	06	ND	98.5
Tripropyleneglycol Methyl Ether	20324338	99.0	03	NS	04	ND	NS	99.0	01	ND	06	ND	
Metals													
Barium	7440393	200	03	19.4	04	32.4	0.0	200	01	283	06	42.6	85.0
Boron	7440428	100	03	2,842	04	2,483	12.6	100	01	6,700	06	2,334	65.2
Chromium	7440473	10.0	03	10.5	04	11.3	0.0	11.1	01	90.6	06	ND	87.7
Silicon	7440213	100	03	5,284	04	6,766	0.0	100	01	27,158	06	6,859	74.7
Strontium	7440246	100	03	193	04	237	0.0	100	01	1,935	06	249	87.1
Titanium	7440326	2.5	03	4.8	04	ND	48.1	2.5	01	69.9	06	ND	96.4
Zinc	7440666	20.0	03	25.2	04	58.6	0.0	20.0	01	494	06	27.1	94.5
Pesticides/Herbicides													
Dichloroprop	120365	1.0	03	NS	04	ND	NS	11.8 /1.0	01	ND	06	ND	
Disulfoton	298044	2.0	03	NS	04	ND	NS	2.0	01	6.1	06	ND	67.2
Dioxins/Furans													
1234678-HpCDD	35822469	50.0 pg/L	03	NS	04	NS	NS	50.0 pg/L	01	NS	06	NS	NS
OCDD	3268879	100 pg/L	03	NS	04	NS	NS	100 pg/L	01	NS	06	NS	NS

Negative percent removal are recorded as 0.0.
NS: Not Sampled   DL: Specific detection limits of sample when there is a non-detect, otherwise it is the method detection limit
ND: Non-detect   SP: Sample point

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Table 8-4: Treatment Technology Performance for Facility 4721 - Subtitle C Hazardous

Pollutant of Interest Subtitle C Hazardous	CAS #	Biological Treatment Unit: Sample Points 1 to 2					
				Influent		Effluent	%
		DL	SP	Conc. (ug/L)	SP	Conc. (ug/L)	Removal
Conventional							
BOD	C-002	2,000	01	877,875	02	47,000	94.7
Oil and Grease	C-036	5,000	01	45,442	02	6,792	85.1
TSS	C-009	4,000	01	191,375	02	53,375	72.1
Nonconventional							
Amenable Cyanide	C-025	10.0	01	ND	02	ND	
Ammonia as Nitrogen	7664417	10.0	01	382,250	02	1,433	99.6
COD	C-004	5,000	01	2,033,750	02	565,750	72.2
Nitrate/Nitrite	C-005	50.0	01	1,770	02	333,375	0.0
TDS	C-010		01	12,275,000	02	12,075,000	1.6
TOC	C-012	1,000	01	562,250	02	189,625	66.3
Total Cyanide	57125	20.0	01	54.1	02	46.1	14.8
Total Phenols	C-020	50.0	01	3,195	02	67.6	97.9
Organics							
1,1-Dichloroethane	75343	10.0	01	31.5	02	ND	68.2
1,4-Dioxane	123911	10.0	01	ND	02	ND	
2-Butanone	78933	50.0	01	6,398	02	ND	99.2
2-Propanone	67641	50.0	01	4,398	02	ND	98.9
2,4-Dimethylphenol	105679	10.0	01	79.0	02	ND	87.4
4-Methyl-2-Pentanone	108101	50.0	01	2,175	02	ND	97.7
Alpha Terpineol	98555	10.0	01	691	02	ND	98.6
Aniline	62533	10.0	01	685	02	ND	98.5
Benzene	71432	10.0	01	127	02	ND	92.2
Benzoic Acid	65850	50.0	01	5,294	02	ND	99.1
Benzyl Alcohol	100516	10.0	01	23.7	02	ND	57.9
Diethyl Ether	60297	50.0	01	104	02	ND	51.8
Ethylbenzene	100414	10.0	01	545	02	ND	98.2
Hexanoic Acid	142621	10.0	01	1,632	02	ND	99.4
Isobutyl Alcohol	78831	10.0	01	ND	02	ND	
M-Xylene	108383	10.0	01	412	02	ND	97.6
Methylene Chloride	75092	10.0	01	49.2	02	ND	79.7
Naphthalene	91203	10.0	01	486	02	ND	97.9
O+P Xylene	136777612	10.0	01	155	02	ND	93.6
O-Cresol	95487	10.0	01	ND	02	ND	
P-Cresol	106445	10.0	01	218	02	ND	95.4
Phenol	108952	10.0	01	1,553	02	ND	99.4
Pyridine	110861	10.0	01	12.0	02	ND	16.5
Toluene	108883	10.0	01	1,468	02	ND	99.3
Trans-1,2-Dichloroethene	156605	10.0	01	52.7	02	ND	81.0
Trichloroethene	79016	10.0	01	ND	02	ND	
Tripropyleneglycol Methyl Ether	20324338	99.0	01	1,756	02	ND	94.4
Vinyl Chloride	75014	10.0	01	15.6	02	ND	36.0
Metals							
Arsenic	7440382	10.0	01	1,492	02	569	61.9
Boron	7440428	100	01	8,839	02	8,449	4.4
Chromium	7440473	10.0	01	86.7	02	46.5	46.4
Copper	7440508	8.0	01	20.6	02	ND	61.2
Lithium	7439932	100	01	277	02	316	0.0
Metals (Cont'd)							
Molybdenum	7439987	10.0	01	227	02	266	0.0
Nickel	7440020	40.0	01	131	02	125	4.1

Table 8-4: Treatment Technology Performance for Facility 4721 - Subtitle C Hazardous (continued)

Pollutant of Interest Subtitle C Hazardous	CAS #	Biological Treatment Unit: Sample Points 1 to 2					
		DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal
Selenium	7782492	15.5	01	20.0	02	ND	22.5
Silicon	7440213	100	01	5,518	02	5,024	9.0
Strontium	7440246	100	01	2,846	02	2,494	12.4
Tin	7440315	30.0	01	30.7	02	ND	2.4
Titanium	7440326	5.0	01	64.5	02	5.3	91.7
Zinc	7440666	20.0	01	253	02	85.3	66.3
Pesticides/Herbicides							
2,4-D	94757	1.0	01	1.2	02	ND	14.0
2,4-DB	94826	2.0	01	3.9	02	ND	48.4
2,4,5-TP	93721	0.2	01	0.5	02	ND	55.1
Dicamba	1918009	0.2	01	1.1	02	0.4	64.2
Dichloroprop	120365	1.0	01	2.1	02	1.3	37.7
MCPA	94746	50.0	01	59.1	02	ND	15.3
MCPP	7085190	50.0	01	153	02	51.9	66.1
Picloram	1918021	0.5	01	0.5	02	ND	2.0
Terbuthylazine	5915413	5.0	01	6.0	02	ND	16.8
Dioxins/Furans							
1234678-HpCDD	35822469	50.0 pg/L	01	588 pg/L	02	NS	NS
1234678-HpCDF	67562394	50.0 pg/L	01	63.3 pg/L	02	NS	NS
OCDD	3268879	100.0 pg/L	01	6,148 pg/L	02	NS	NS
OCDF	39001020	100.0 pg/L	01	237 pg/L	02	NS	NS

Negative percent removal are recorded as 0.0.

NS: Not Sampled

ND: Non-detect

DL: Specific detection limits of sample when there is a non-detect, otherwise it is the method detection limit

SP: Sample point.

Table 8-5: Treatment Technology Performance for Facility 4759 - Subtitle C Hazardous

Pollutant of Interest Subtitle C Hazardous	CAS #	Bioligical Treatment Unit Only: Sample Points 2 to 3						Entire Treatment System Sample Points 1 to 3					
		DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal	DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal
Conventional													
BOD	C-002	2,000	02	2,650,000	03	62,800	97.6	2,000	01	2,664,000	03	62,800	97.6
Oil and Grease	C-036	5,000	02	30,167	03	9,333	69.1	5,000	01	37,333	03	9,333	75.0
TSS	C-009	4,000	02	47,300	03	90,000	0.0	4,000	01	122,600	03	90,000	26.6
Nonconventional													
Amenable Cyanide	C-025	20.0	02	NS	03	271	NS	20.0	01	3,990	03	271	93.2
Ammonia as Nitrogen	7664417	10.0	02	194,400	03	155,500	20.0	10.0	01	209,400	03	155,500	25.7
COD	C-004	5,000	02	5,200,000	03	1,180,000	77.3	5,000	01	5,006,000	03	1,180,000	76.4
Nitrate/Nitrite	C-005	50.0	02	263,196	03	240,423	8.7	50.0	01	259,242	03	240,423	7.3
TDS	C-010		02	17,230,000	03	15,680,000	9.0		01	16,360,000	03	15,680,000	4.2
TOC	C-012	1,000	02	1,800,000	03	284,700	84.2	1,000	01	1,804,000	03	284,700	84.2
Total Cyanide	57125	20.0	02	869	03	796	8.5	20.0	01	9,756	03	796	91.9
Total Phenols	C-020	50.0	02	97,340	03	155	99.8	50.0	01	97,860	03	155	99.8
Organics													
1,1-Dichloroethane	75343	10.0	02	23.8	03	ND	58.0	10.0	01	26.7	03	ND	62.5
1,4-Dioxane	123911	10.0	02	1,935	03	702	63.7	10.0	01	2,003	03	702	65.0
2-Butanone	78933	50.0	02	1,633	03	ND	96.9	50.0	01	1,724	03	ND	97.1
2-Propanone	67641	50.0	02	3,254	03	65.0	98.0	50.0	01	3,634	03	65.0	98.2
2,4-Dimethylphenol	105679	10.0	02	1,798	03	201	88.8	10.0	01	1,550	03	201	87.0
4-Methyl-2-Pentanone	108101	50.0	02	1,009	03	ND	95.1	50.0	01	1,027	03	ND	95.1
Alpha Terpineol	98555	10.0	02	ND	03	ND		10.0	01	ND	03	ND	
Aniline	62533	10.0	02	577	03	ND	98.3	10.0	01	533	03	ND	98.1
Benzene	71432	10.0	02	32.0	03	ND	68.7	10.0	01	36.2	03	ND	72.4
Benzoic Acid	65850	50.0	02	70,690	03	ND	99.9	50.0	01	64,957	03	ND	99.9
Benzyl Alcohol	100516	10.0	02	859	03	ND	98.8	10.0	01	878	03	ND	98.9
Diethyl Ether	60297	50.0	02	ND	03	ND		50.0	01	ND	03	ND	
Ethylbenzene	100414	10.0	02	13.8	03	ND	27.3	10.0	01	15.8	03	ND	36.5
Hexanoic Acid	142621	10.0	02	5,266	03	ND	99.8	10.0	01	3,640	03	ND	99.7
Isobutyl Alcohol	78831	10.0	02	127	03	ND	92.1	10.0	01	138	03	ND	92.8
M-Xylene	108383	10.0	02	10.6	03	ND	5.3	10.0	01	10.7	03	ND	6.2
Methylene Chloride	75092	10.0	02	604	03	10.3	98.3	10.0	01	661	03	10.3	98.4
Naphthalene	91203	10.0	02	22.0	03	ND	54.6	10.0	01	24.8	03	ND	59.6
O+P Xylene	136777612	10.0	02	ND	03	ND		10.0	01	ND	03	ND	
O-Cresol	95487	10.0	02	61.2	03	ND	83.7	10.0	01	188	03	ND	94.7
P-Cresol	106445	10.0	02	5,119	03	ND	99.8	10.0	01	5,022	03	ND	99.8
Phenol	108952	10.0	02	54,808	03	29.7	100	10.0	01	65,417	03	29.7	100
Pyridine	110861	10.0	02	309	03	ND	96.8	10.0	01	301	03	ND	96.7
Toluene	108883	10.0	02	120	03	ND	91.7	10.0	01	136	03	ND	92.6
Trans-1,2-Dichloroethene	156605	10.0	02	ND	03	ND		10.0	01	ND	03	ND	
Trichloroethene	79016	10.0	02	ND	03	ND		10.0	01	ND	03	ND	
Tripropyleneglycol Methyl Ether	20324338	99.0	02	ND	03	ND		99.0	01	1,021	03	ND	90.3
Vinyl Chloride	75014	10.0	02	ND	03	ND		10.0	01	ND	03	ND	
Metals													
Arsenic	7440382	10.0	02	389	03	312	19.9	10.0	01	584	03	312	46.6
Boron	7440428	100	02	2,706	03	2,486	8.1	100	01	2,918	03	2,486	14.8
Chromium	7440473	10.0	02	158	03	82.4	47.8	10.0	01	415	03	82.4	80.2

Table 8-5: Treatment Technology Performance for Facility 4759- Subtitle C Hazardous (continued)

Pollutant of Interest Subtitle C Hazardous	CAS #	Biologiccal Treatment Unit Only: Sample Points 2 to 3						Entire Treatment System Sample Points 1 to 3					
		DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal	DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal
Metals (cont.)													
Copper	7440508	25.0	02	61.1	03	76.4	0.0	25.0	01	139	03	76.4	45.2
Lithium	7439932	100	02	253	03	239	5.5	100	01	266	03	239	10.2
Molybdenum	7439987	10.0	02	13,710	03	13,130	4.2	10.0	01	13,260	03	13,130	1.0
Nickel	7440020	40.0	02	2,014	03	1,878	6.8	40.0	01	2,060	03	1,878	8.8
Selenium	7782492	5.0	02	191	03	190	0.2	5.0	01	178	03	190	0.0
Silicon	7440213	100	02	6,924	03	6,153	11.1	100	01	6,036	03	6,153	0.0
Strontium	7440246	100	02	105	03	94.4	9.9	100	01	284	03	94.4	66.8
Tin	7440315	30.0	02	800	03	723	9.5	30.0	01	908	03	723	20.4
Titanium	7440326	5.0	02	5.1	03	2.4	52.1	5.0	01	23.3	03	2.4	89.6
Zinc	7440666	20.0	02	26.7	03	47.2	0.0	20.0	01	126	03	47.2	62.5
Pesticides/Herbicides													
2,4-D	94757	1.0	02	NS	03	11.8	NS	1.0	01	11.2	03	11.8	0.0
2,4-DB	94826	2.0	02	NS	03	4.3	NS	2.0	01	43.8	03	4.3	90.2
2,4,5-TP	93721	0.2	02	NS	03	0.4	NS	0.2	01	0.5	03	0.4	18.3
Dicamba	1918009	0.2	02	NS	03	0.9	NS	0.2	01	41.6	03	0.9	97.9
Dichloroprop	120365	1.0	02	NS	03	4.7	NS	1.0	01	18.3	03	4.7	74.3
MCPA	94746	50.0	02	NS	03	182	NS	50.0	01	332	03	182	45.3
MCPP	7085190	50.0	02	NS	03	288	NS	50.0	01	662	03	288	56.5
Picloram	1918021	0.5	02	NS	03	2.5	NS	0.5	01	4.5	03	2.5	45.2
Terbuthylazine	5915413	5.0	02	NS	03	28.4	NS	5.0	01	97.6	03	28.4	70.9
Dioxins/Furans													
1234678-HpCDD	35822469	50.0 pg/L	02	NS	03	ND	NS	50.0 pg/L	01	ND	03	ND	
1234678-HpCDF	67562394	50.0 pg/L	02	NS	03	ND	NS	50.0 pg/L	01	ND	03	ND	
OCDD	3268879	100 pg/L	02	NS	03	ND	NS	100 pg/L	01	ND	03	100 pg/L	
OCDF	39001020	100 pg/L	02	NS	03	ND	NS	100 pg/L	01	ND	03	ND	

Negative percent removal are recorded as 0.0.

NS: Not Sampled

ND: Non-detect

DL: Specific detection limits of sample when there is a non-detect, otherwise it is the method detection limit

SP: Sample point.

Table 8-6: Treatment Technology Performance for Facility 4687 - Subtitle D Municipal

Pollutant of Interest Subtitle D Municipal	CAS #	Single-Stage Reverse Osmosis Treatment System Only: Sample Point 1 to 2					Entire Treatment System: Sample Point 1 to 3				
		DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal	DL	SP	Influent Conc. (ug/L)	SP	Effluent Conc. (ug/L)	% Removal
Conventional													
BOD	C-002	2,000	01	1,182,000	02	54,000	95.4	2,000	01	1,182,000	03	5,400	99.5
TSS	C-009	4,000	01	171,800	02	ND	97.7	4,000	01	171,800	03	ND	97.7
Noconventional													
Ammonia as Nitrogen	7664417	10.0	01	58,480	02	13,600	76.7	10.0	01	58,480	03	608	99.0
COD	C-004	5,000	01	1,526,000	02	72,200	95.3	5,000	01	1,526,000	03	11,400	99.3
Hexavalent Chromium	18540299	10.0	01	28.0	02	ND	64.3	10.0	01	28.0	03	ND	64.3
Nitrate/Nitrite	C-005	50.0	01	1,300	02	666	48.8	50.0	01	1,300	03	502	61.4
TDS	C-010		01	2,478,000	02	116,600	95.3	10,000	01	2,478,000	03	ND	99.6
TOC	C-012	1,000	01	642,600	02	25,000	96.1	10,000	01	642,600	03	ND	98.4
Total Phenols	C-020	50.0	01	1,262	02	316	75.0	50.0	01	1,262	03	62.8	95.0
Organics													
1,4-Dioxane	123911	10.8 /14.9	01	ND	02	ND		10.8 /10.0	01	ND	03	ND	
2-Butanone	78933	50.0	01	3,250	02	1,774	45.4	50.0	01	3,250	03	372	88.6
2-Propanone	67641	50.0	01	1,580	02	1,842	0.0	50.0	01	1,580	03	470	70.3
4-Methyl-2-Pentanone	108101	50.5	01	382	02	ND	86.8	50.0	01	382	03	ND	86.9
Alpha Terpineol	98555	10.0	01	44.5	02	ND	77.5	10.0	01	44.5	03	ND	77.5
Benzoic Acid	65850	50.0	01	7,685	02	96.3	98.8	50.0	01	7,685	03	ND	99.4
Hexanoic Acid	142621	10.0	01	5,818	02	118	98.0	10.0	01	5,818	03	ND	99.8
Methylene Chloride	75092	10.0	01	ND	02	ND		10.0	01	ND	03	ND	
N,N-Dimethylformamide	68122	10.0	01	ND	02	ND		10.0	01	ND	03	ND	
O-Cresol	95487	10.0	01	ND	02	ND		10.0	01	ND	03	ND	
P-Cresol	106445	10.0	01	797	02	253	68.3	10.0	01	797	03	22.3	97.2
Phenol	108952	10.0	01	702	02	185	73.6	10.0	01	702	03	29.3	95.8
Toluene	108883	10.0	01	376	02	112	70.2	10.0	01	376	03	15.1	96.0
Tripropyleneglycol Methyl Ether	20324338	99.0	01	1,207	02	ND	91.8	99.0	01	1,207	03	ND	91.8
Metals													
Barium	7440393	200	01	280	02	5.6	98.0	200	01	280	03	1.4	99.5
Boron	7440428	100	01	1,808	02	830	54.1	100	01	1,808	03	101	94.4
Chromium	7440473	9.0	01	ND	02	ND		9.0	01	ND	03	ND	
Silicon	7440213	100	01	4,362	02	511	88.3	100	01	4,362	03	355	91.9
Strontium	7440246	100	01	1,406	02	ND	92.9	100	01	1,406	03	ND	92.9
Titanium	7440326	4.0	01	ND	02	ND		4.0	01	ND	03	ND	
Zinc	7440666	10.9 /9.0	01	ND	02	ND		10.9 /10.0	01	ND	03	ND	
Pesticides/Herbicides													
Dichloroprop	120365	1.0	01	6.1	02	ND	83.6	1.0	01	6.1	03	ND	83.6
Disulfoton	298044	2.0	01	14.3	02	ND	86.1	2.0	01	14.3	03	ND	86.1
Dioxins/Furans													
1234678-HpCDD	35822469	49.8 pg/L	01	ND	02	NS	NS	49.8 pg/L	01	ND	03	NS	NS
OCDD	3268879	99.5 pg/L	01	ND	02	NS	NS	99.5 pg/L	01	ND	03	NS	NS

Negative percent removal are recorded as 0.0.
NS: Not Sampled   DL: Specific detection limits of sample when there is a non-detect, otherwise it is the method detection limit
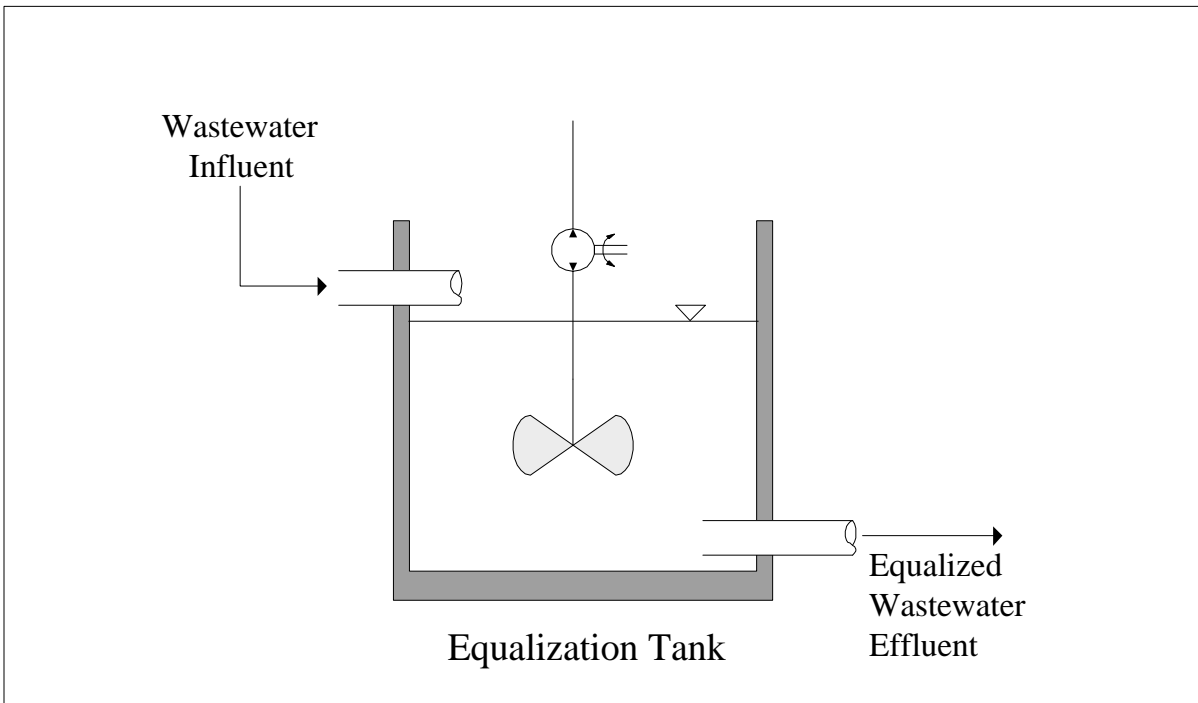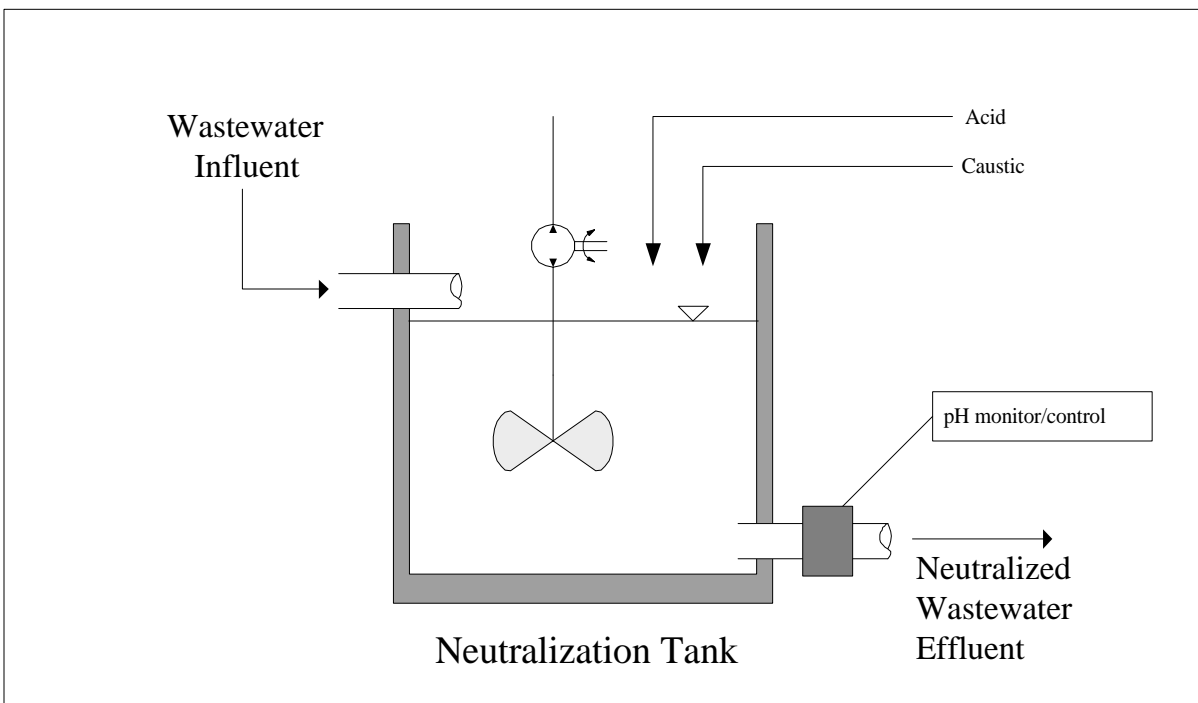ND: Non-detect   SP: Sample point.

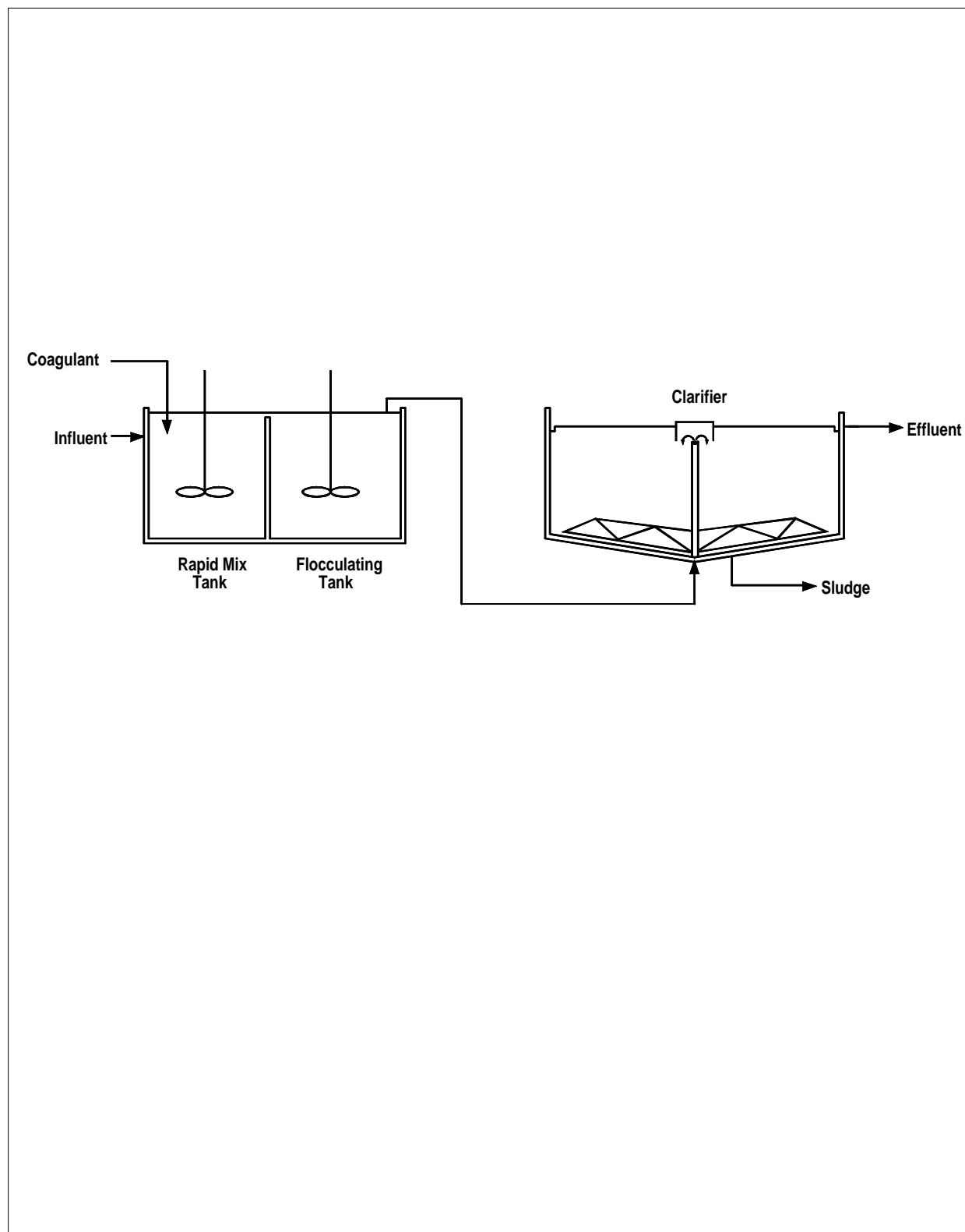Figure 8-1: Equalization

Figure 8-2: Neutralization

Figure 8-3: Clarification System Incorporating Coagulation and Flocculation
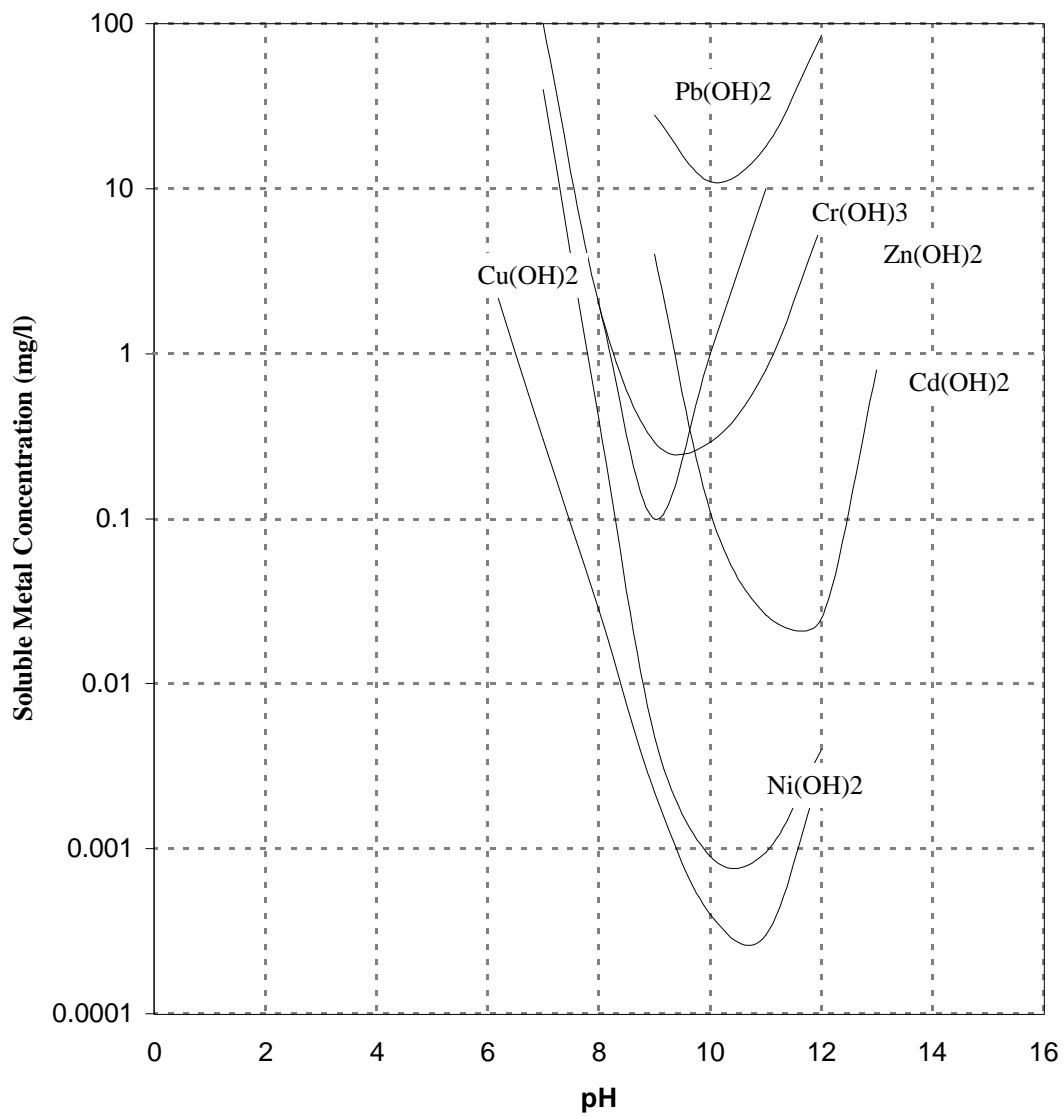
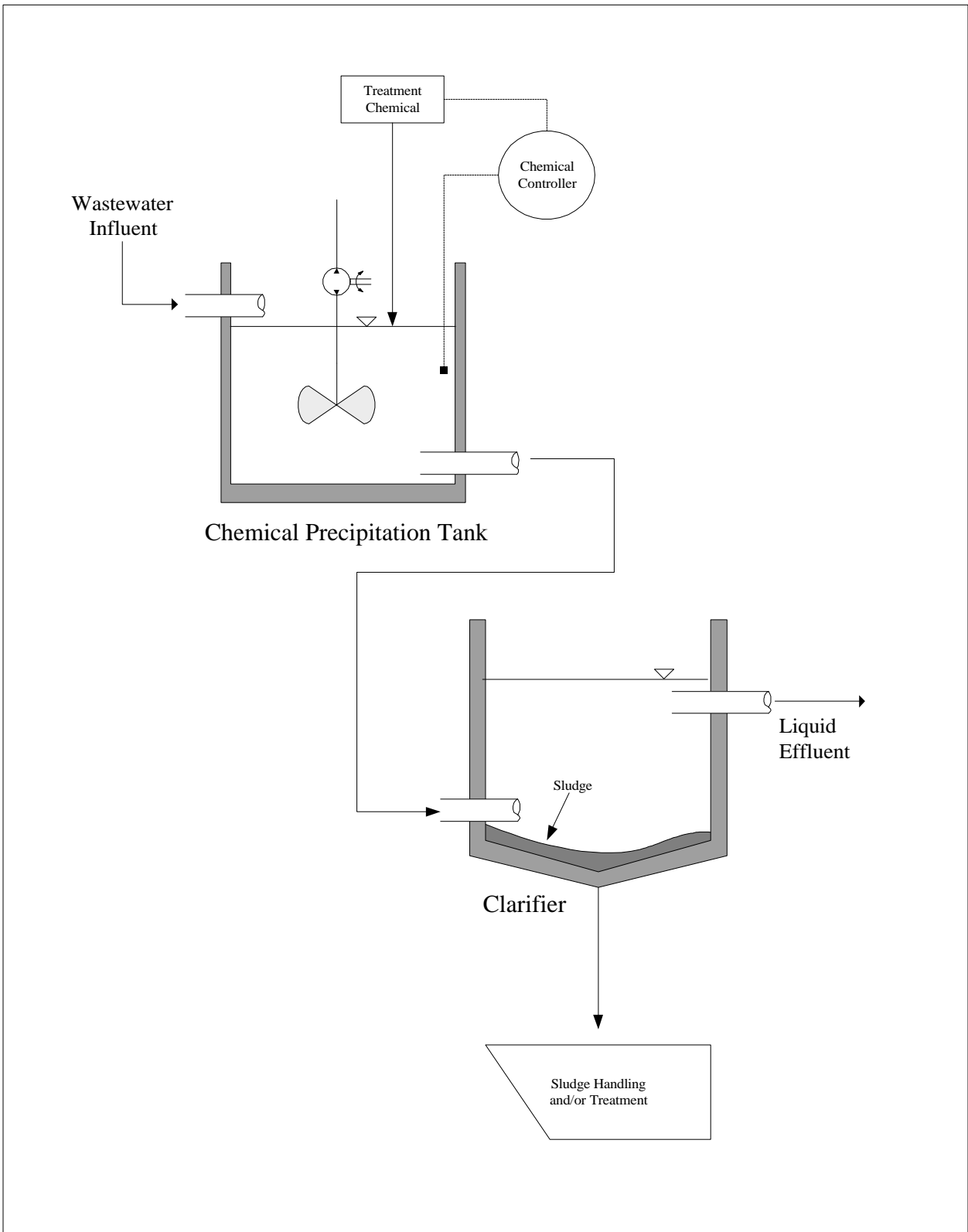Figure 8-4: Calculated Solubilities of Metal Hydroxides
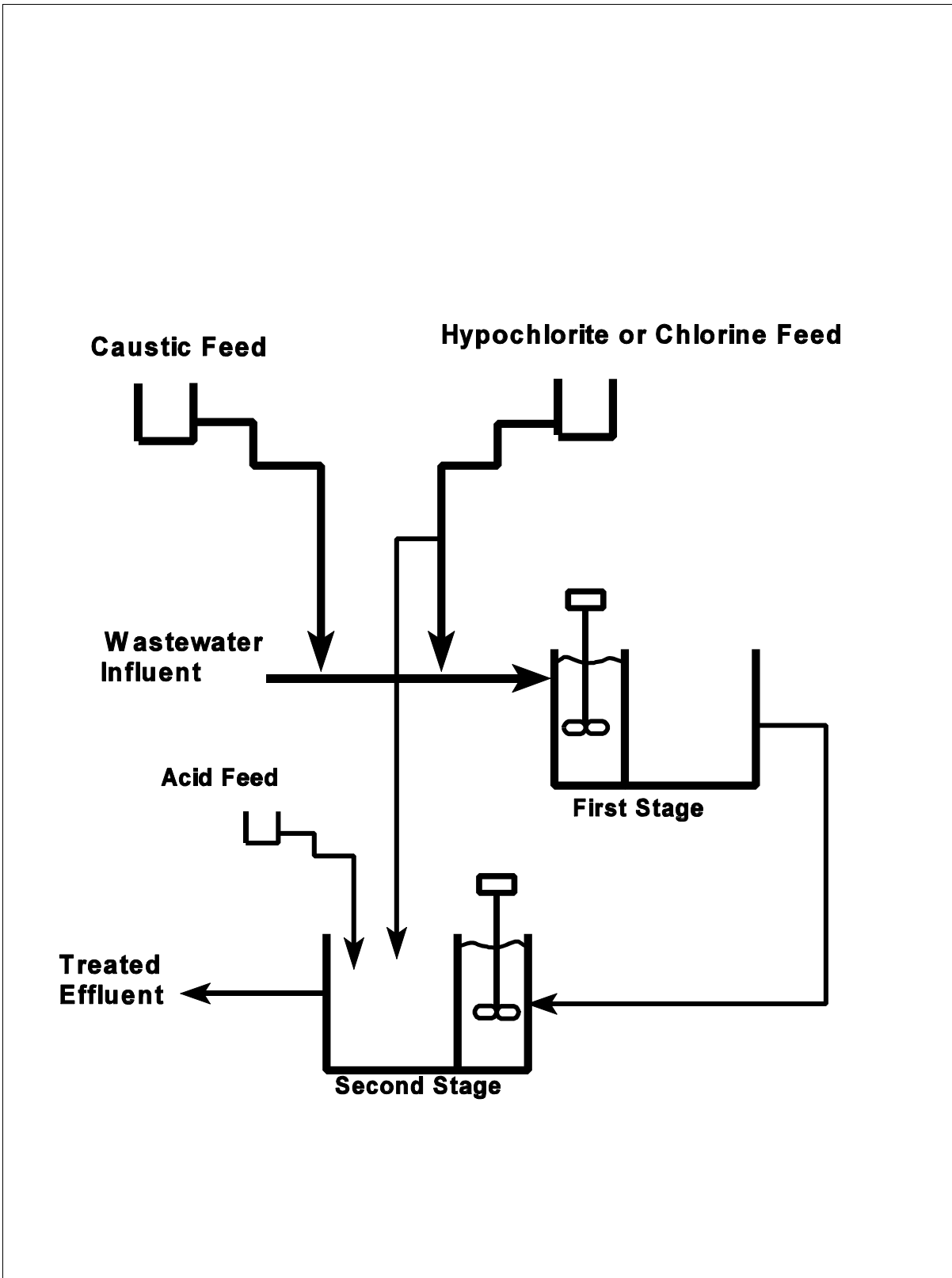
Figure 8-5: Chemical Precipitation System Design

Figure 8-6: Cyanide Destruction

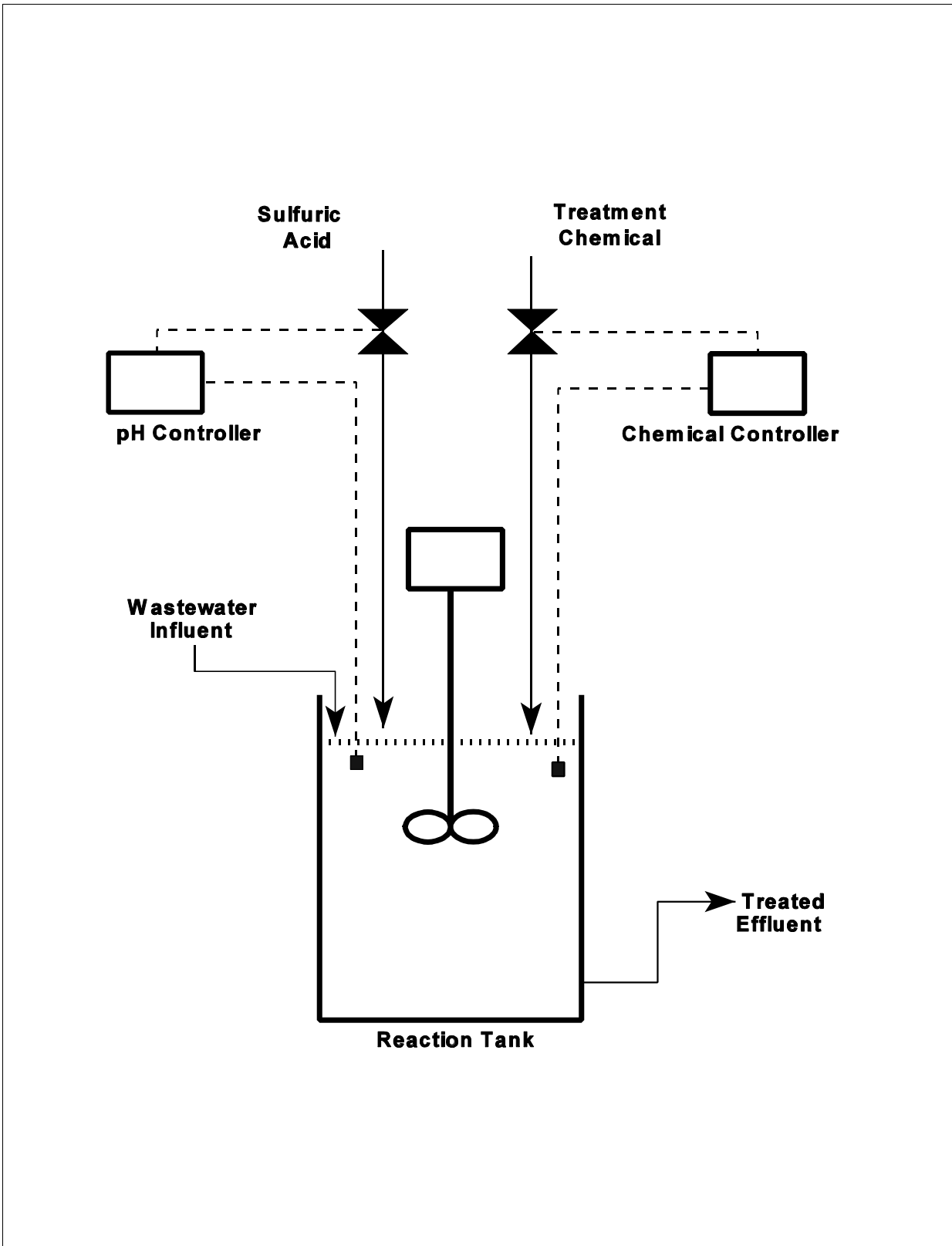Figure 8-7: Chromium Reduction

Off-gas

Wastewater
Influent

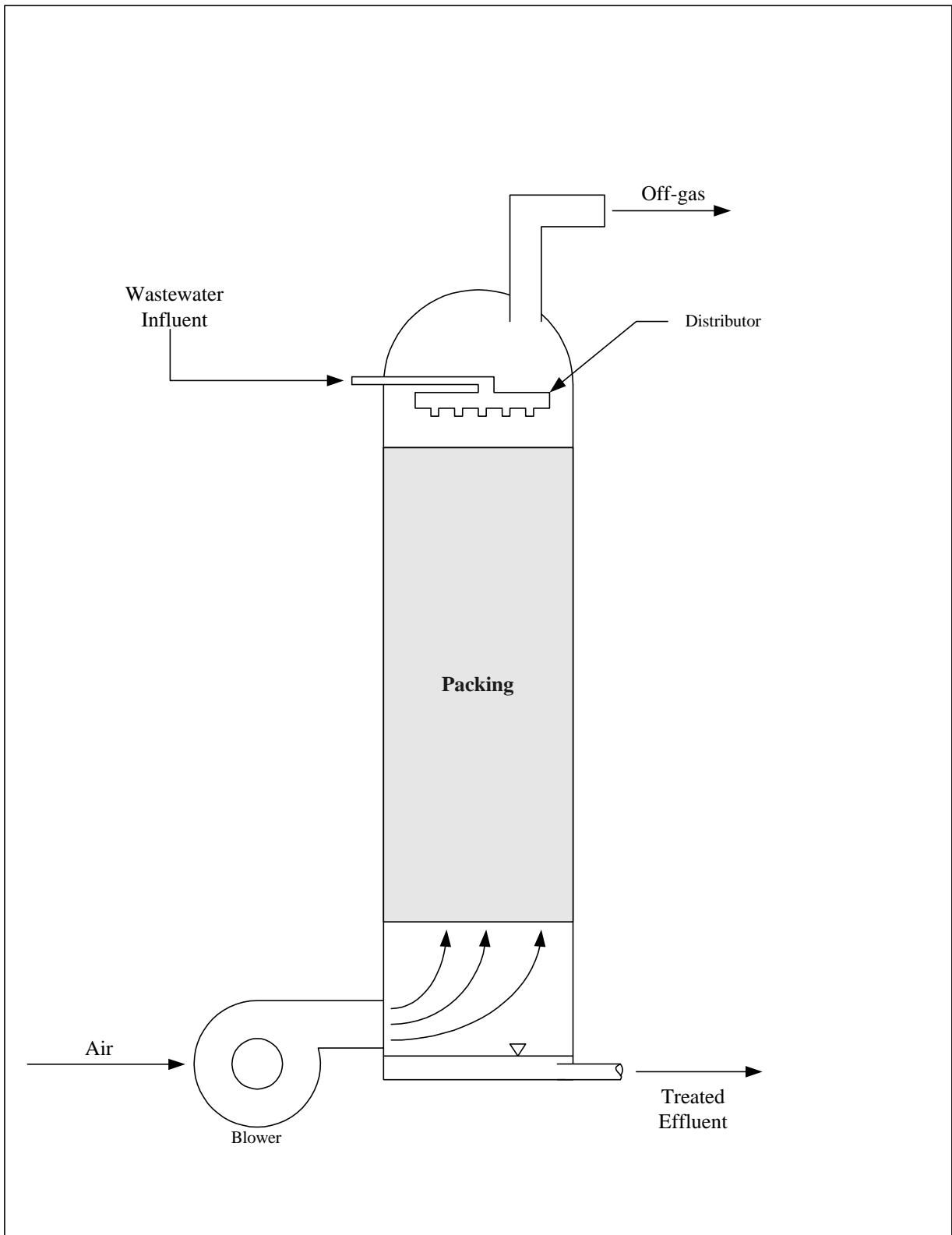Distributor

Packing

Air

Blower

Treated
Effluent

Figure 8-8: Typical Air Stripping System
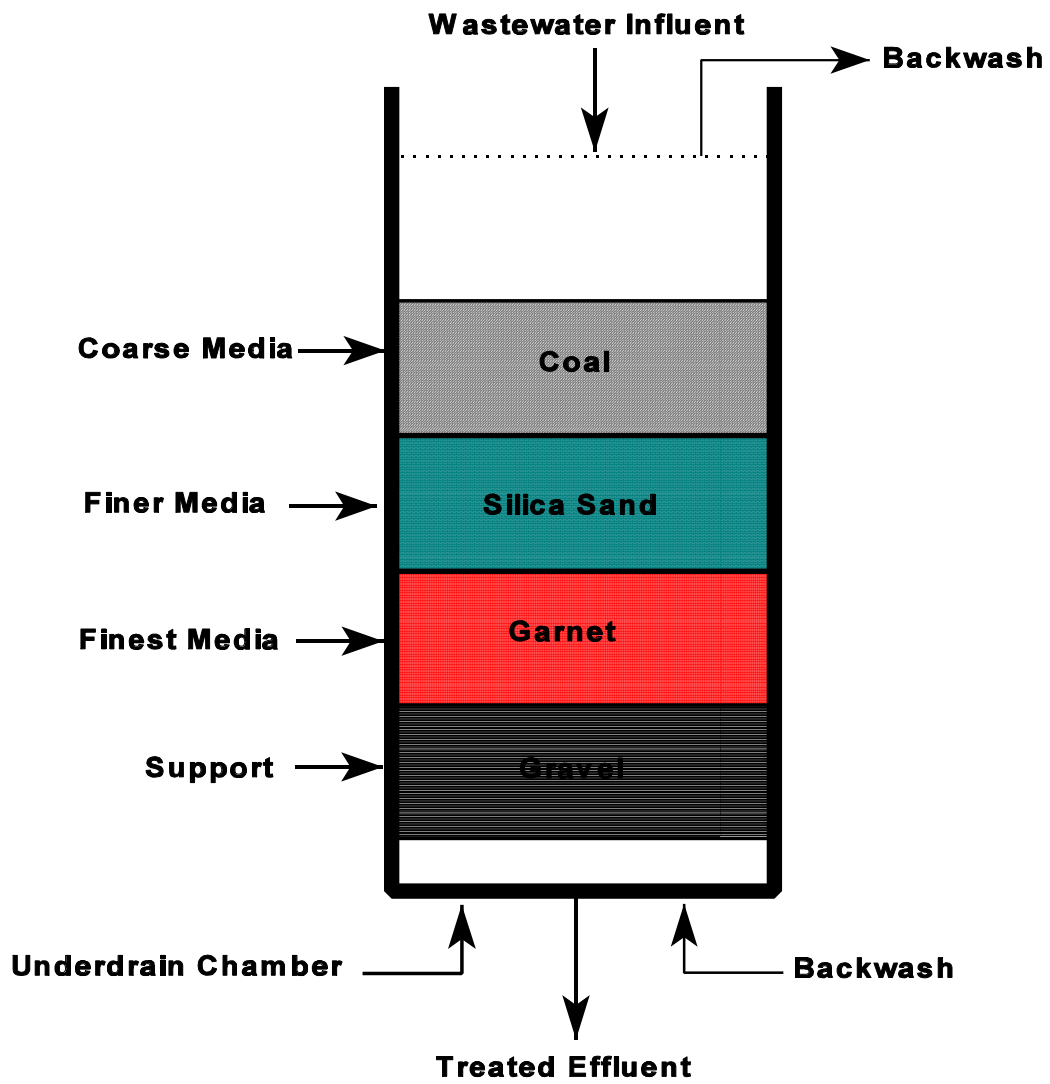
Figure 8-9: Multimedia Filtration

Permeate (Treated Effluent)

Wastewater
Feed

Concentrate

Membrane Cross-section
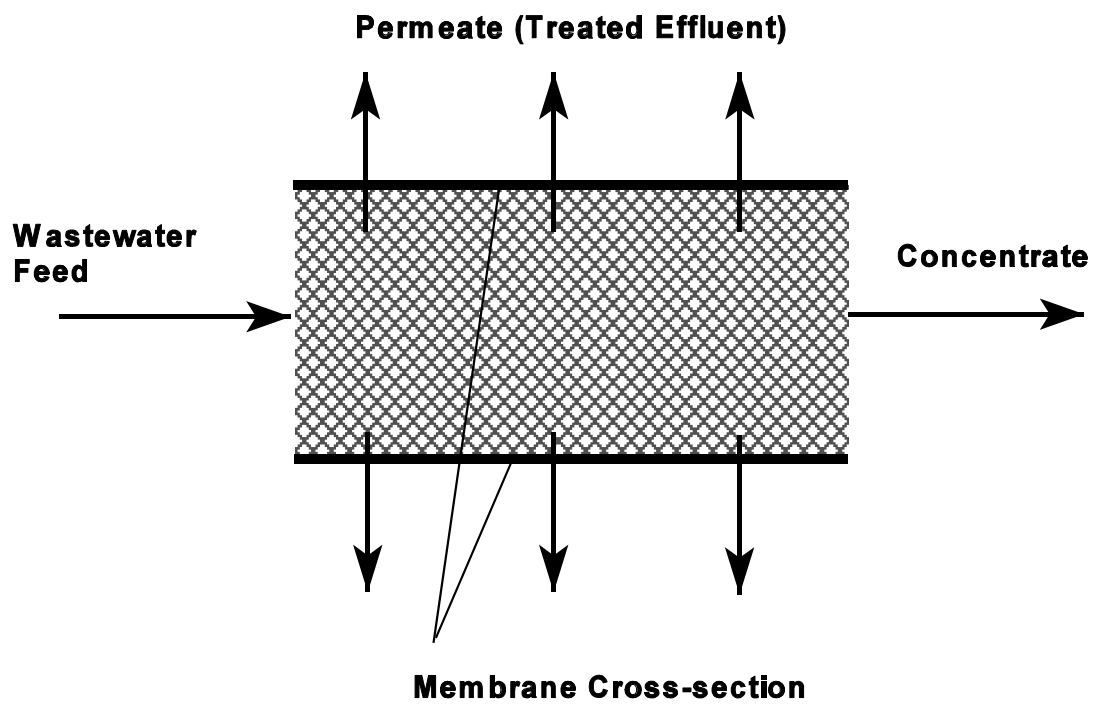
Figure 8-10: Ultrafiltration System Diagram
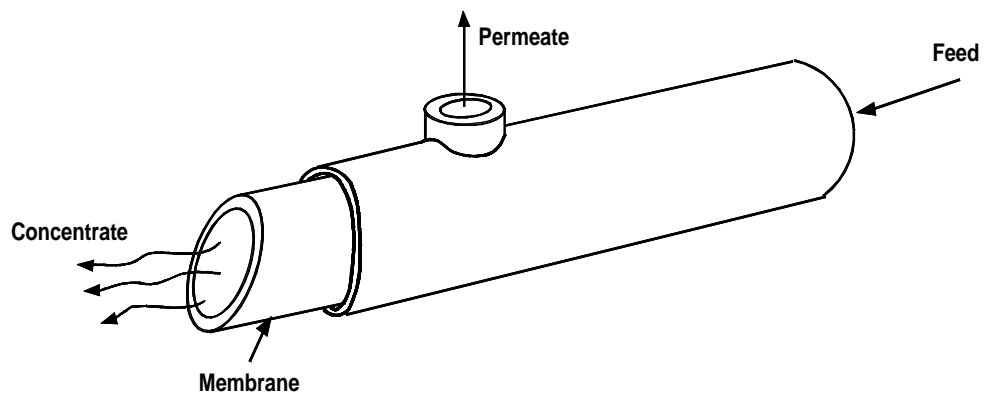
Figure 8-11: Tubular Reverse Osmosis Module
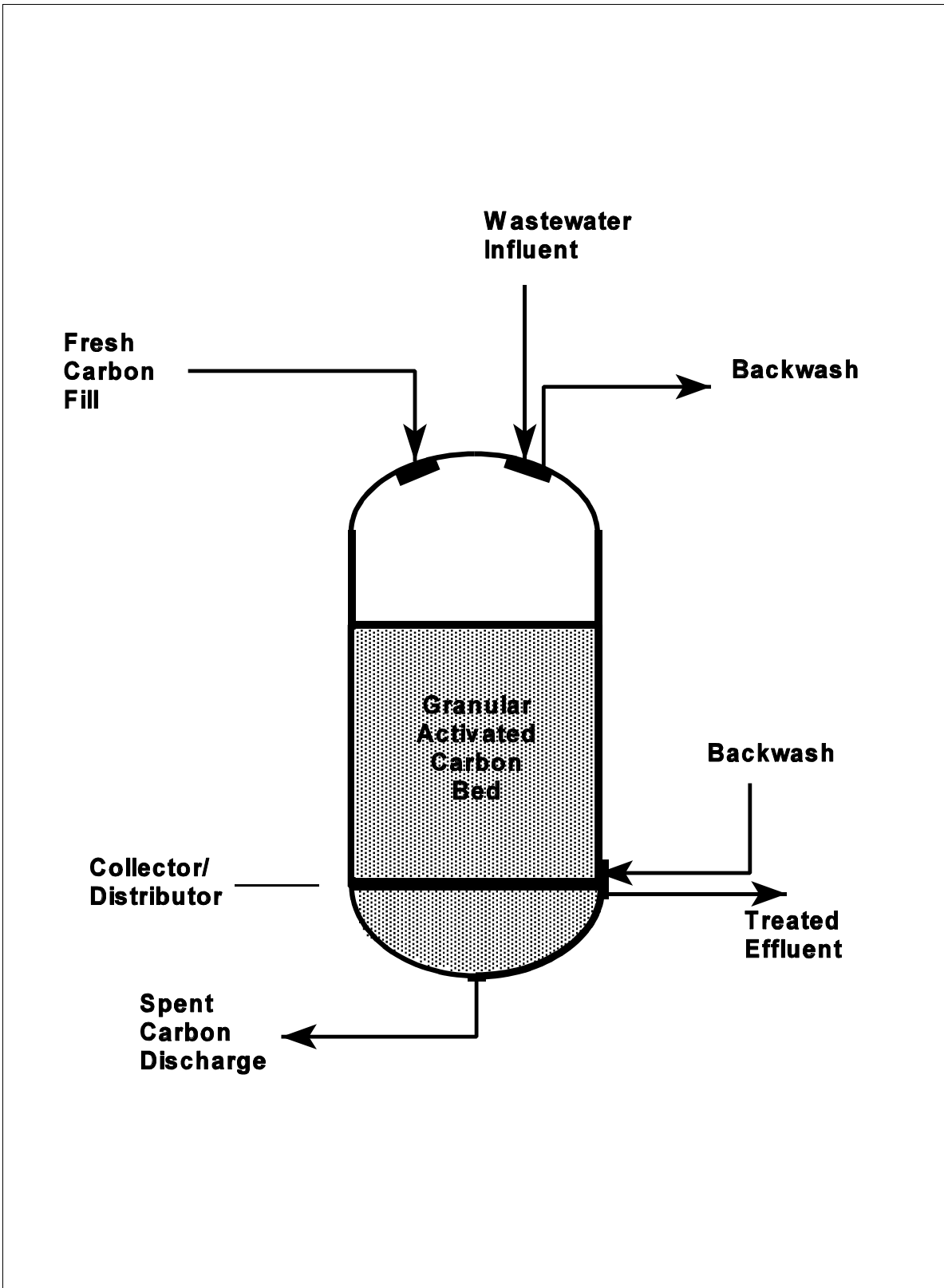
Figure 8-12: Granular Activated Carbon Adsorption

Figure 8-13: Ion Exchange

Surface Aerators
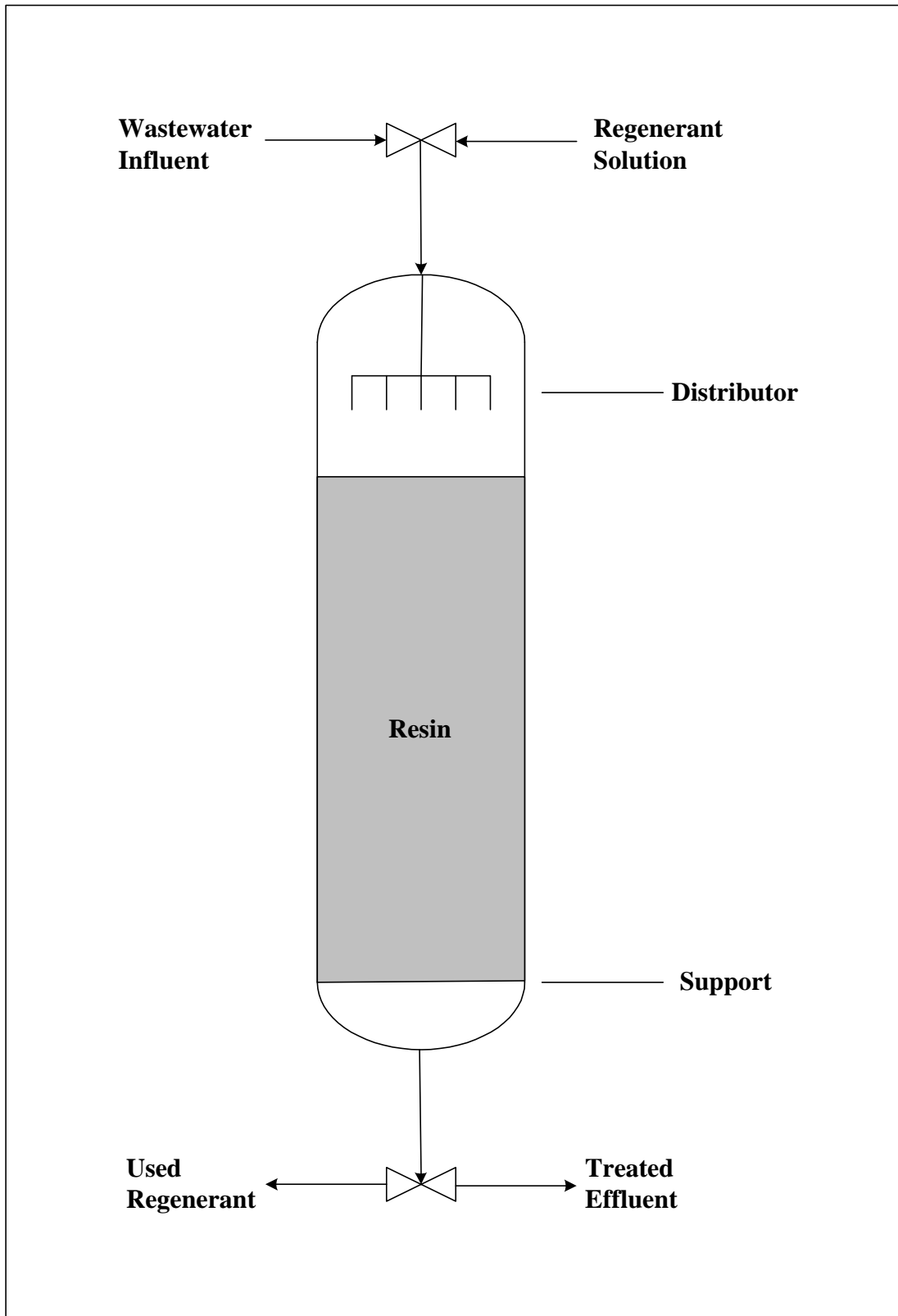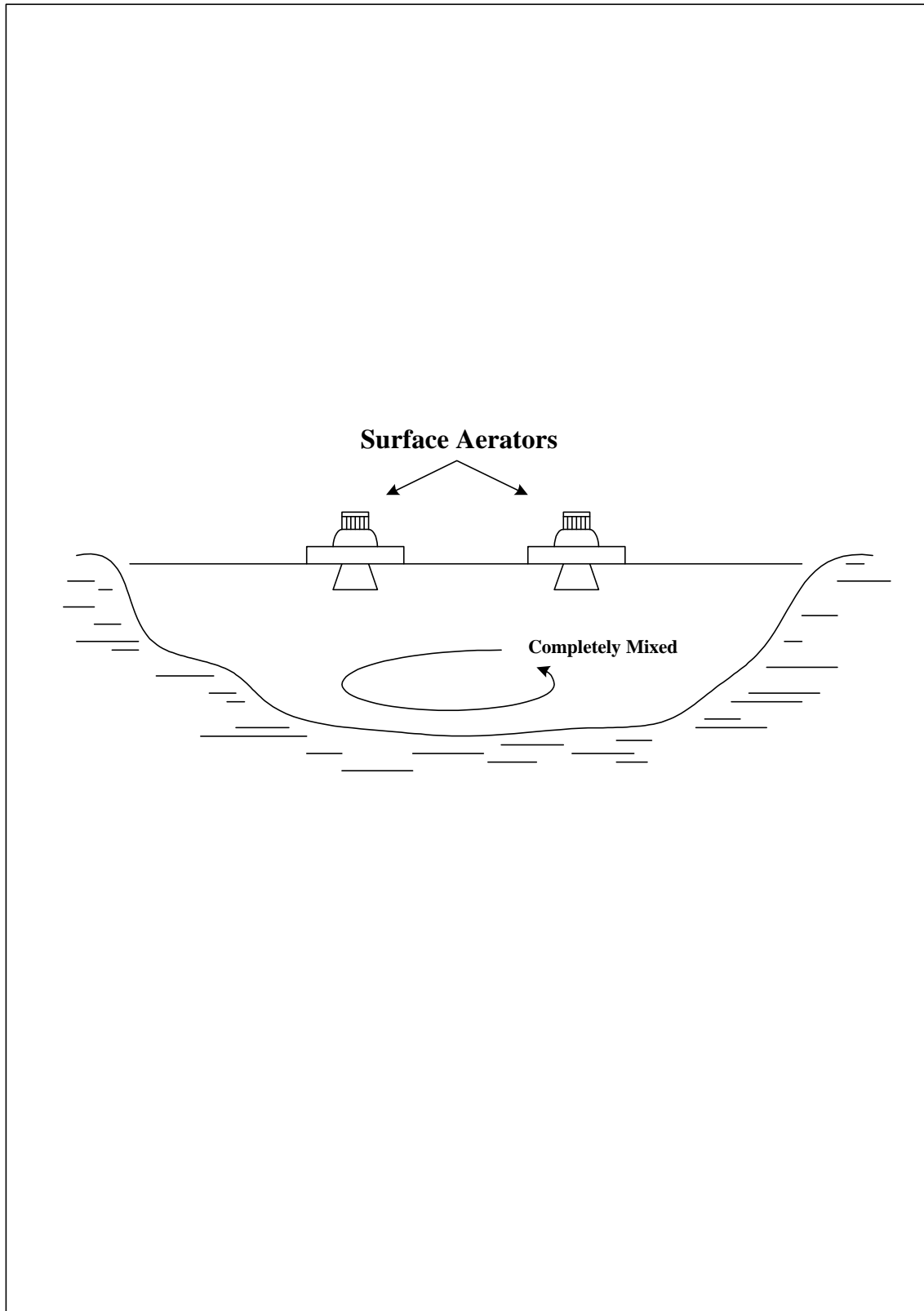
Completely Mixed

Figure 8-14: Aerated Lagoon
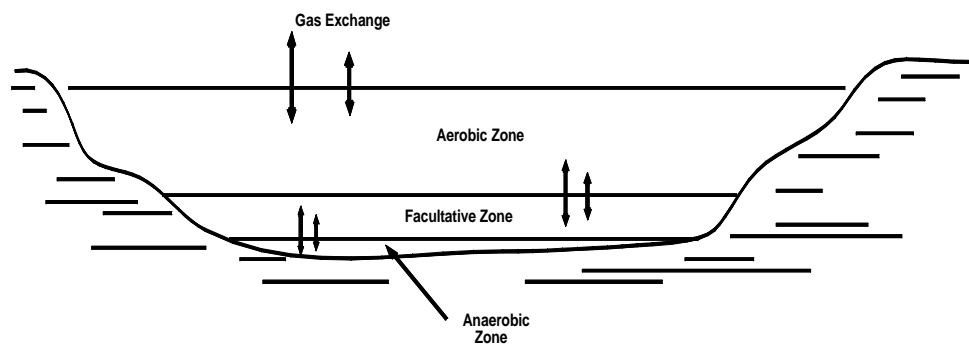
Figure 8-15: Facultative Pond
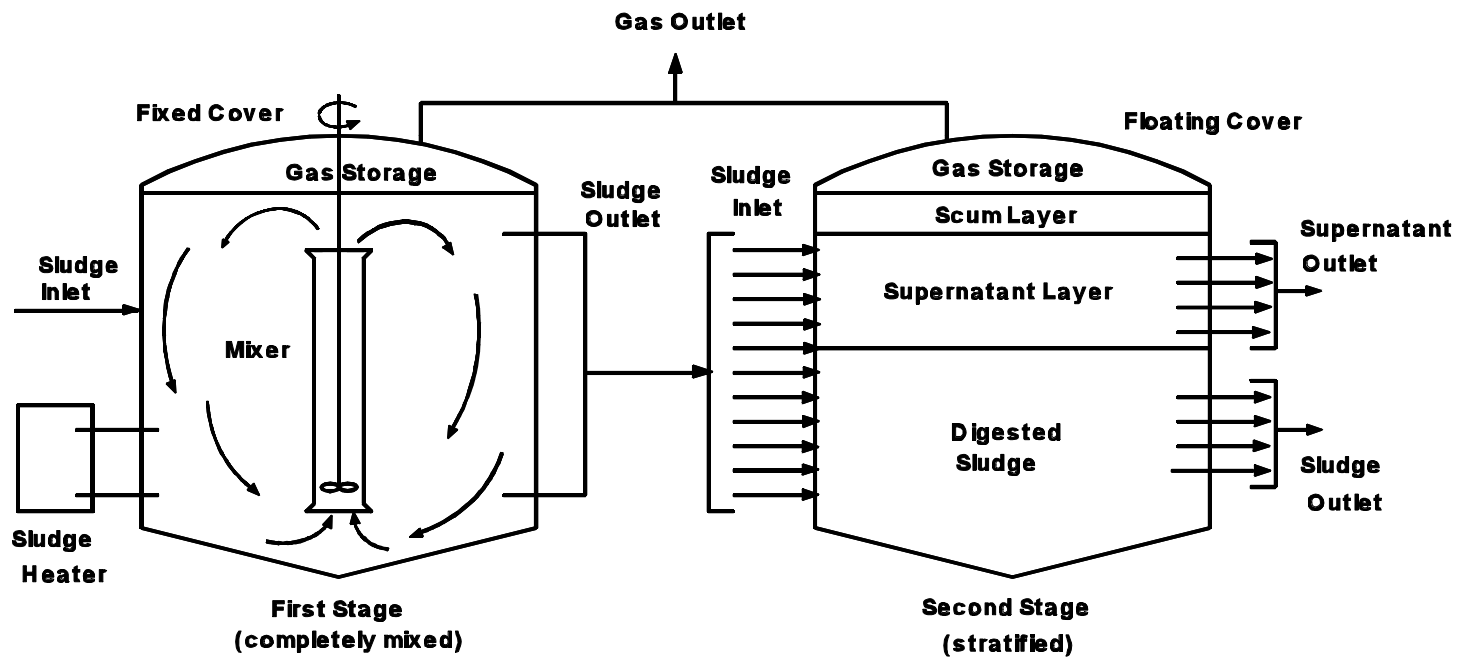
Figure 8-16: Completely Mixed Digestor System
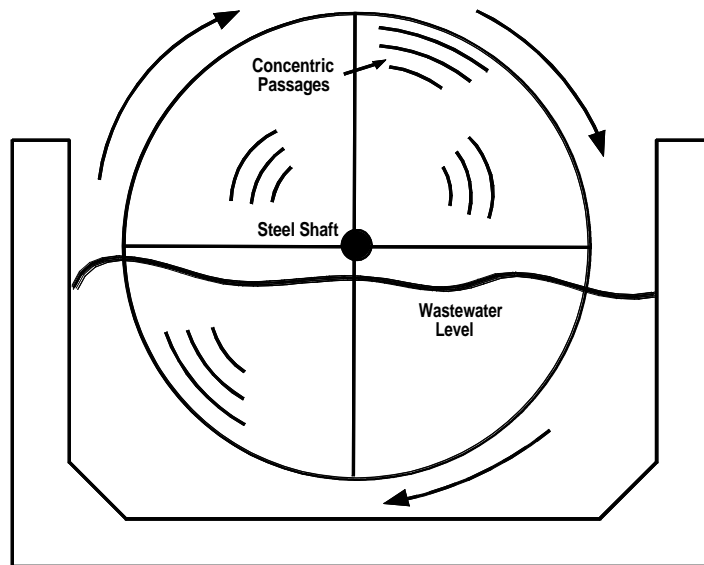
Figure 8-17: Rotating Biological Contactor Cross-Section
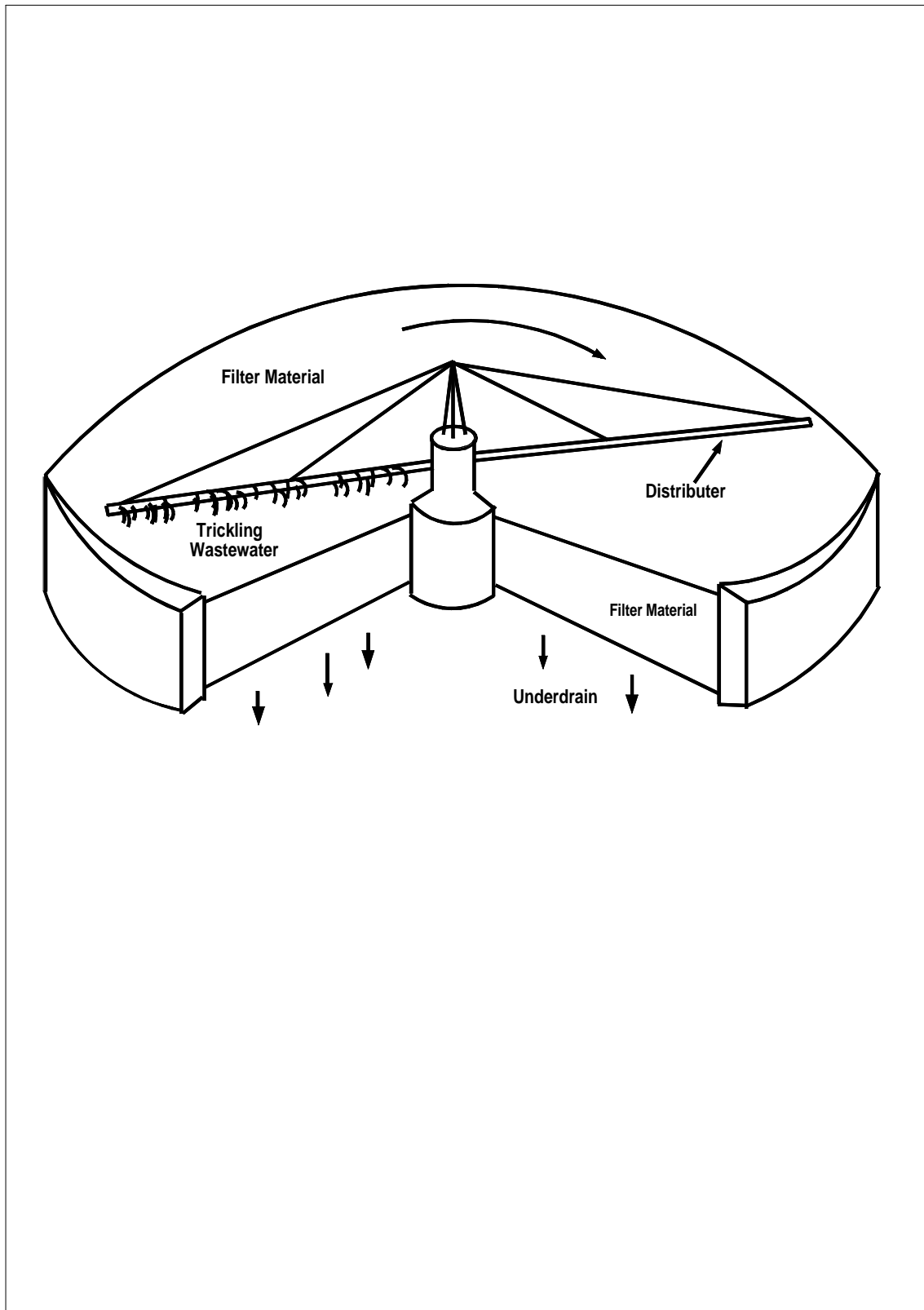
Figure 8-18: Trickling Filter
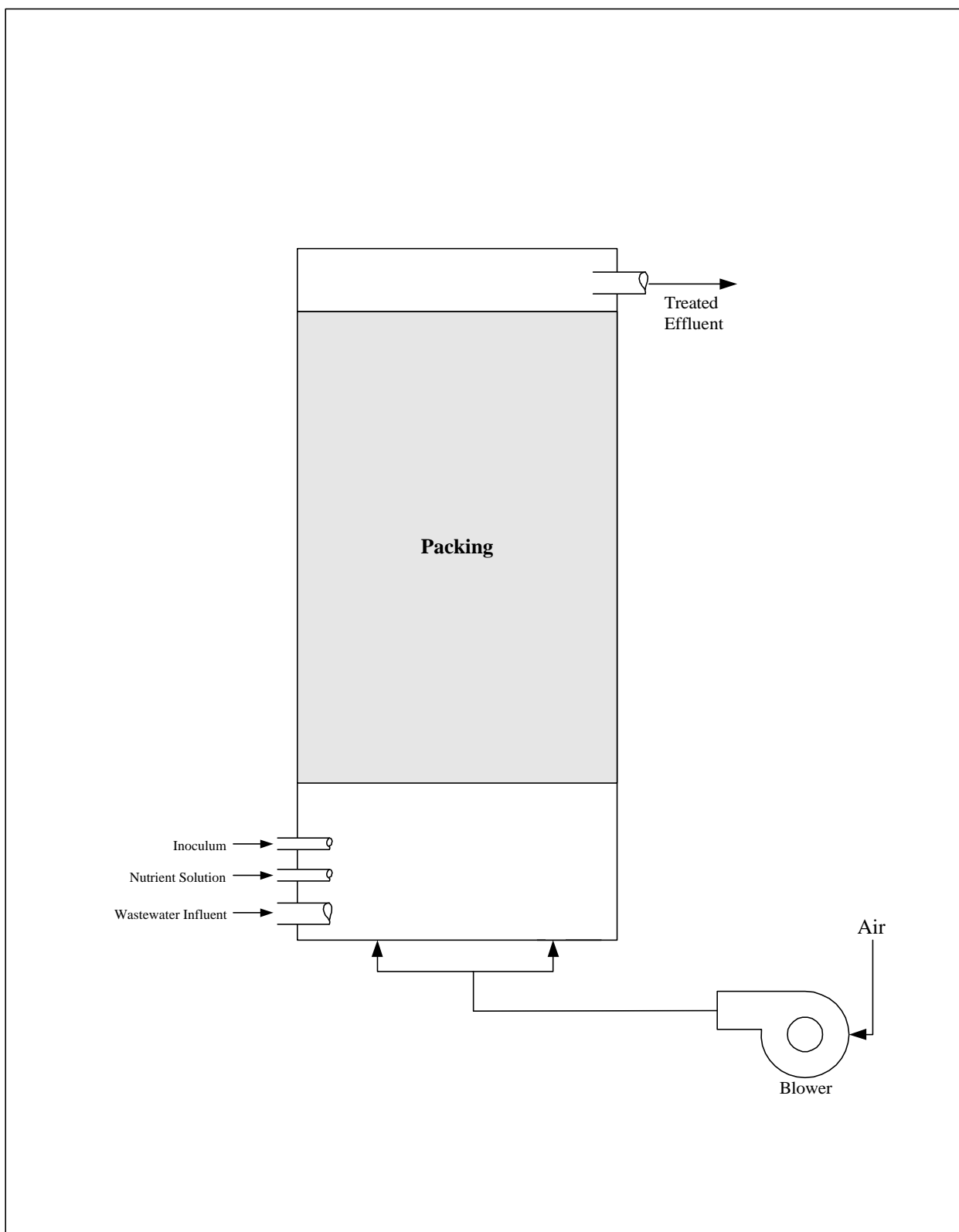
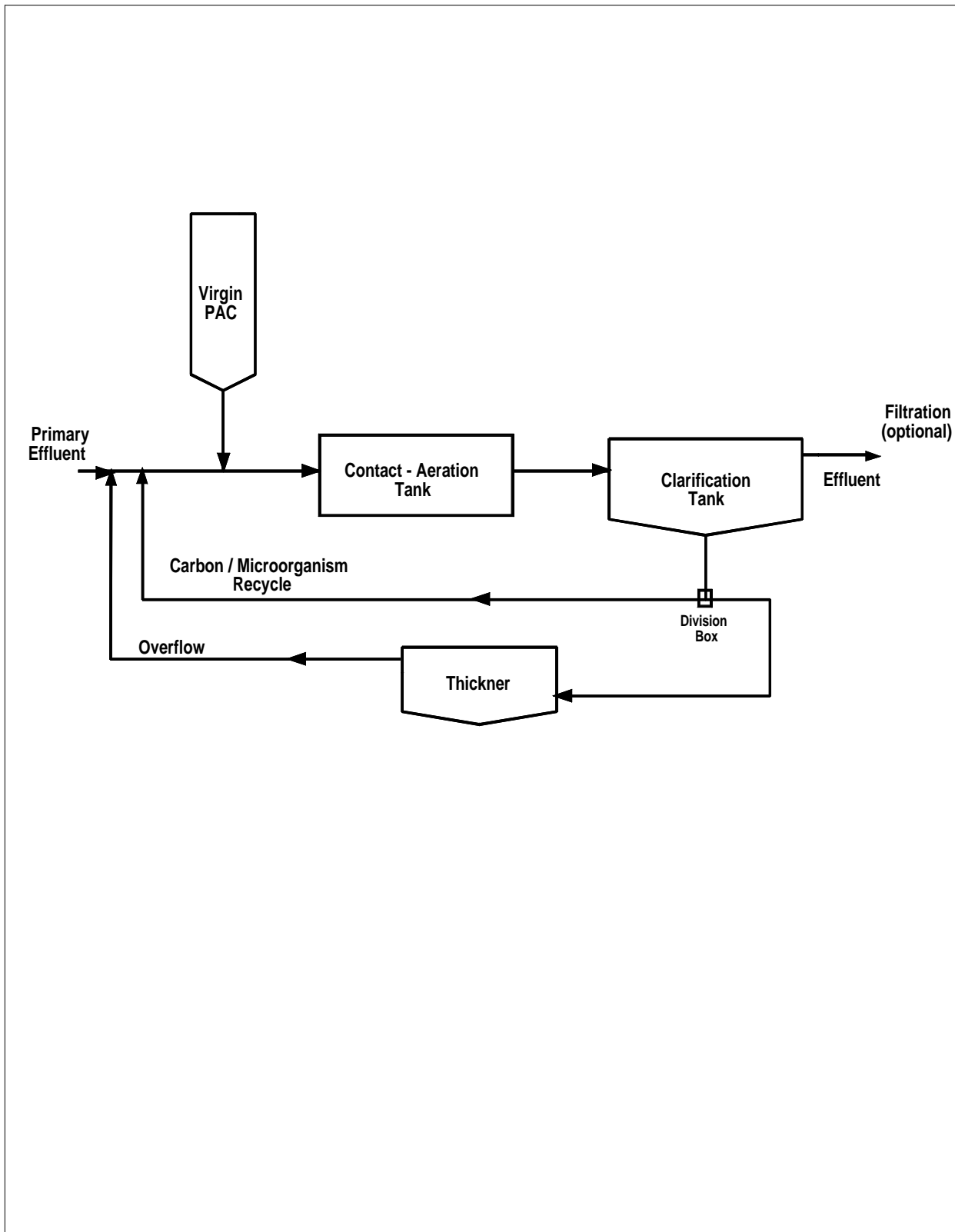Figure 8-19: Fluidized Bed Reactor
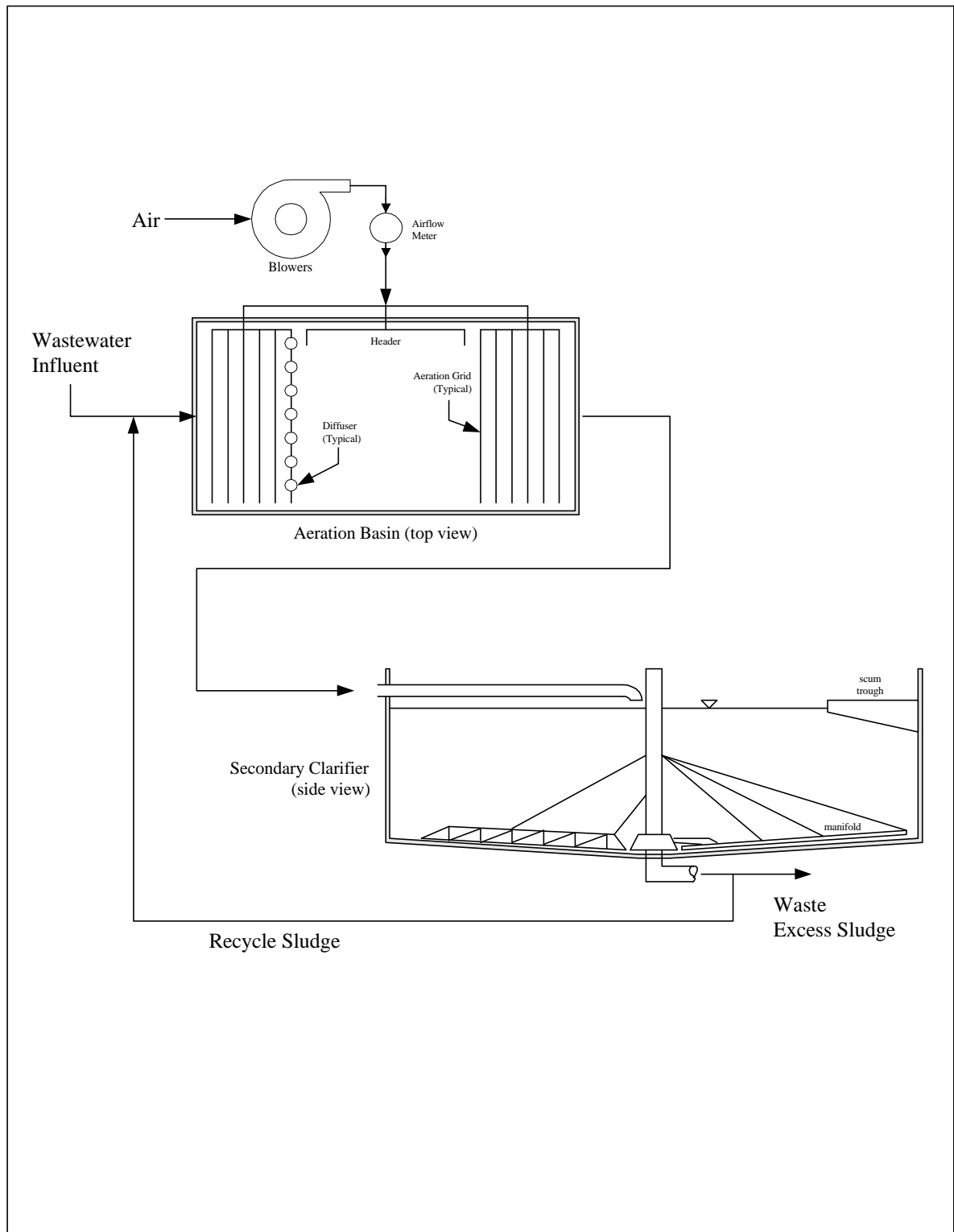
Figure 8-20: Activated Sludge System

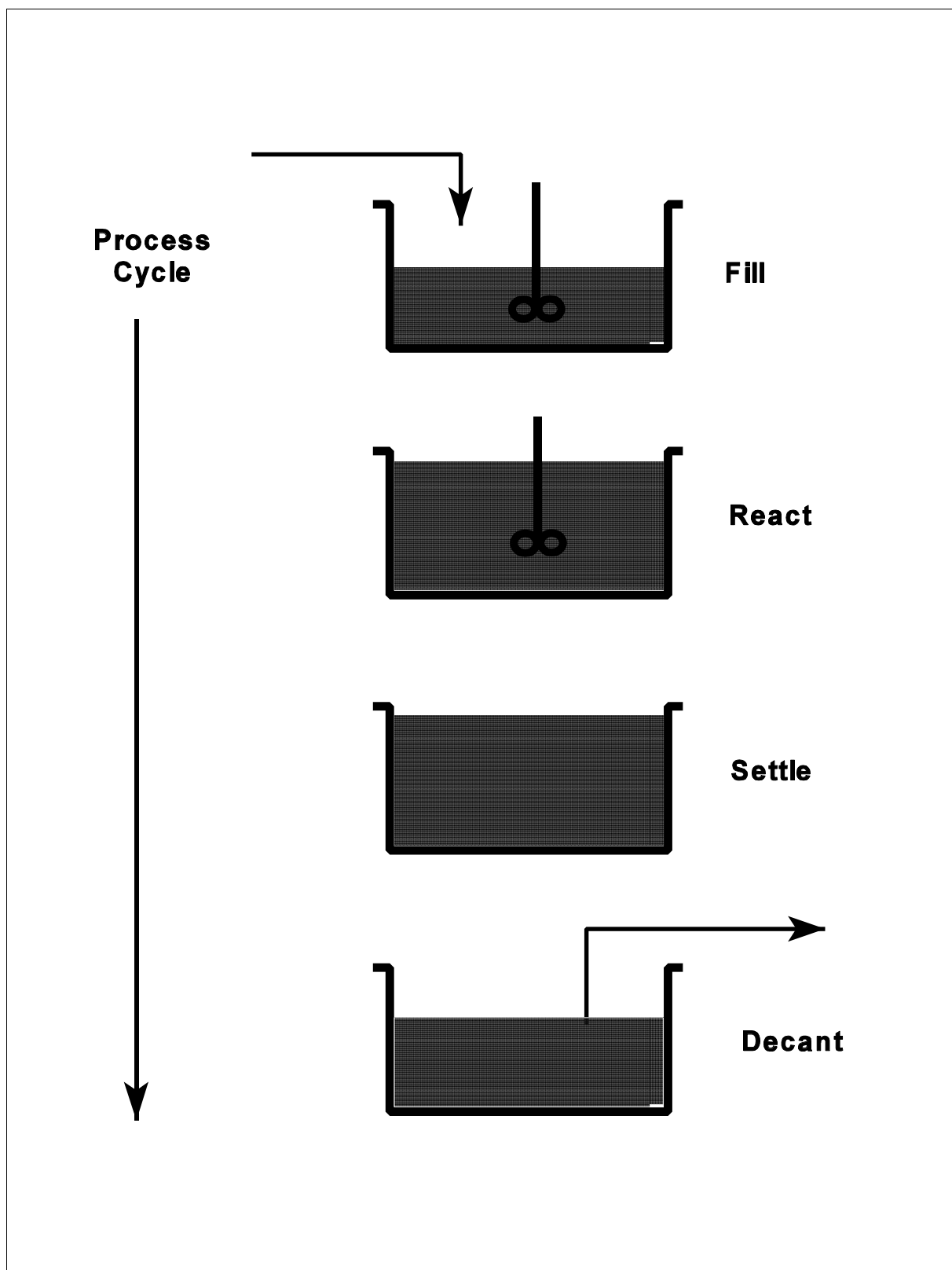Figure 8-21: Powder Activated Carbon Treatment System

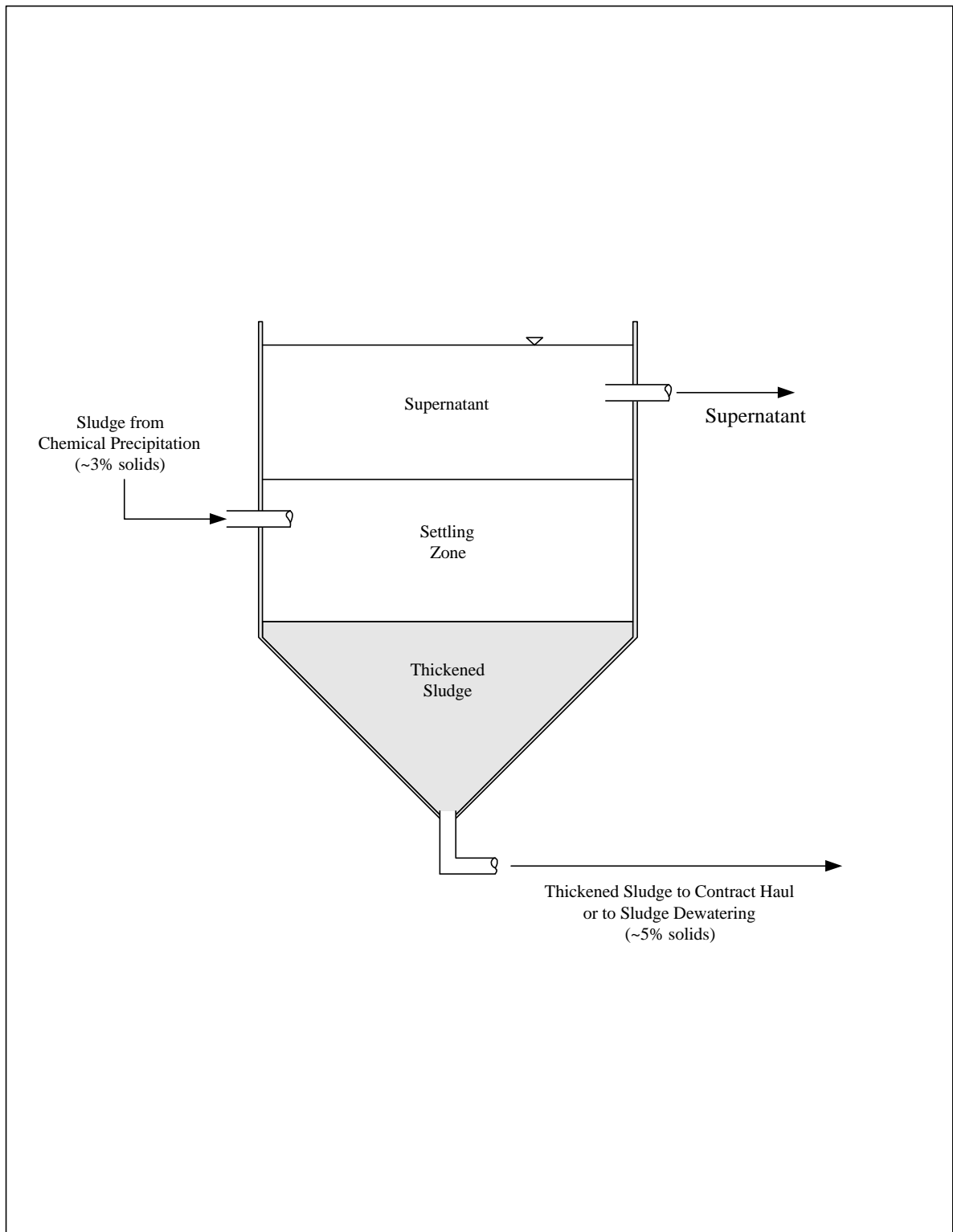Figure 8-22: Sequencing Batch Reactor Process Diagram
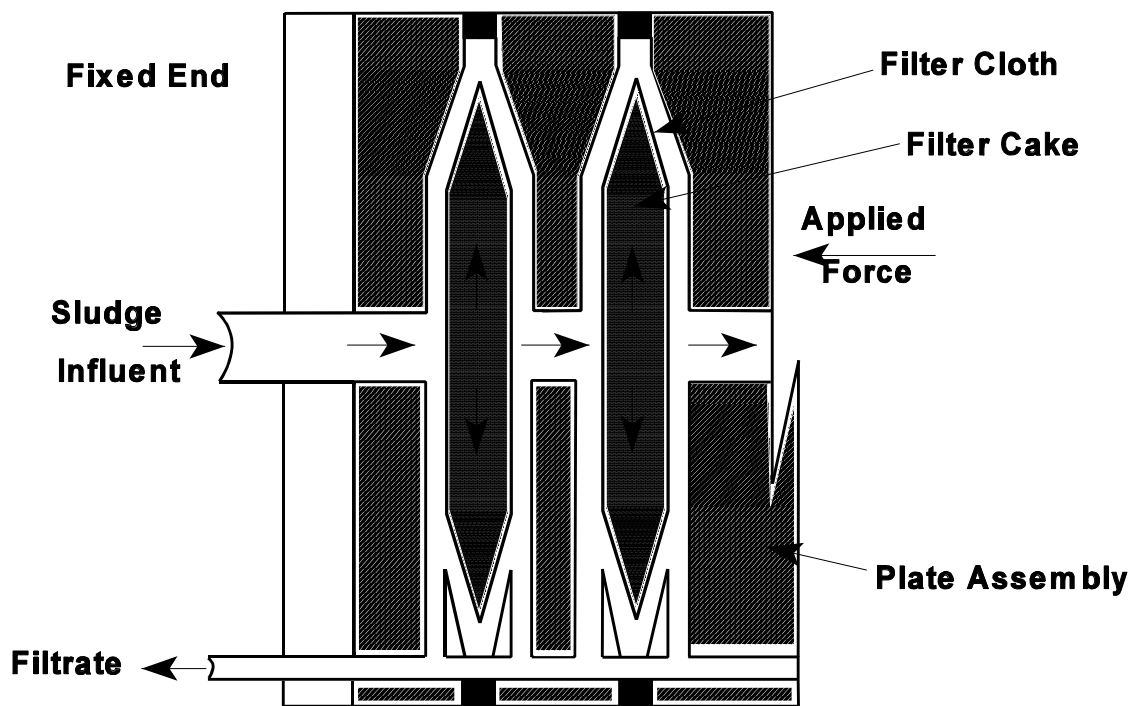
Figure 8-23: Gravity Thickening

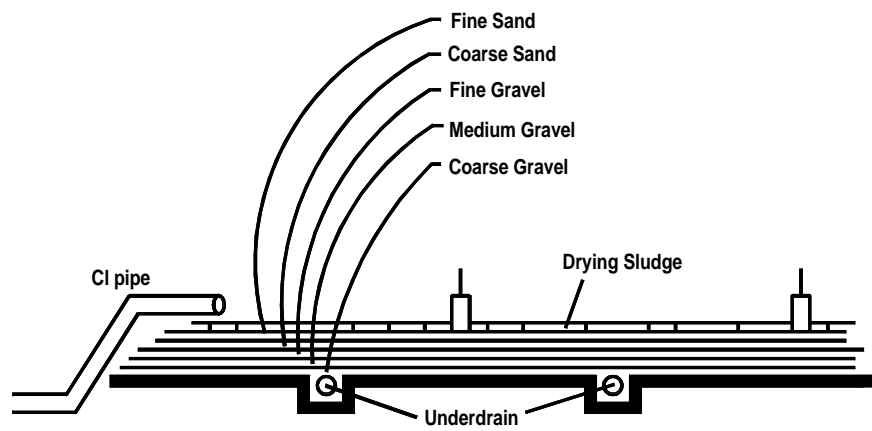Figure 8-24: Plate-and-Frame Pressure Filtration System Diagram
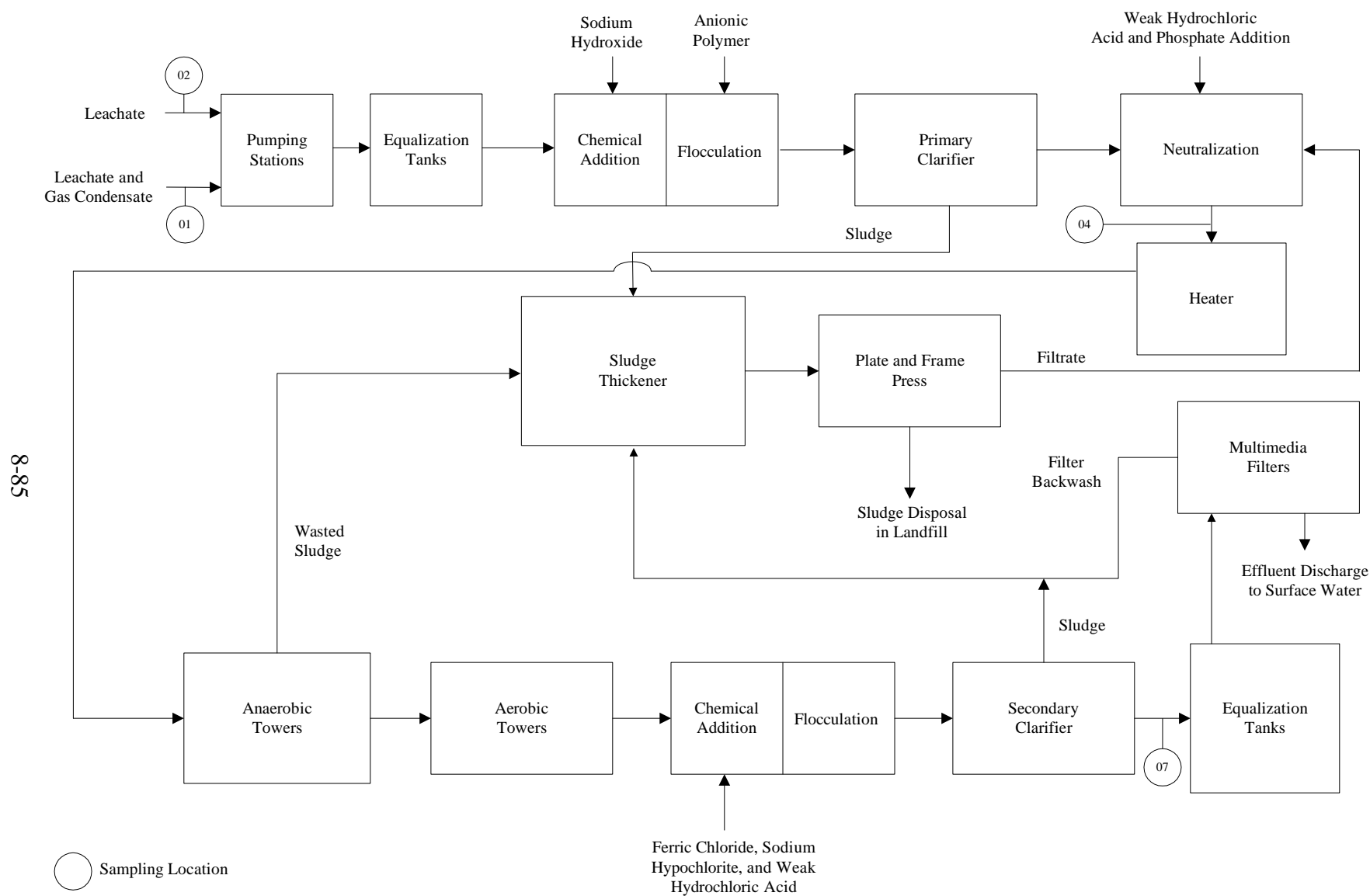
Figure 8-25: Drying Bed

Figure 8-26: EPA Sampling Episode 4626 - Landfill Waste Treatment System Block Flow Diagram with Sampling Locations

Figure 8-27: EPA Sampling Episode 4667 - Landfill Waste Treatment System Block Flow Diagram with Sampling Locations

Leachate and
Off-Site
Waste → [Influent Equalization Feed Tanks (10)] → (01) → [Sequencing Batch Reactor (SBR) (3)] → To POTW (02)

Sludge

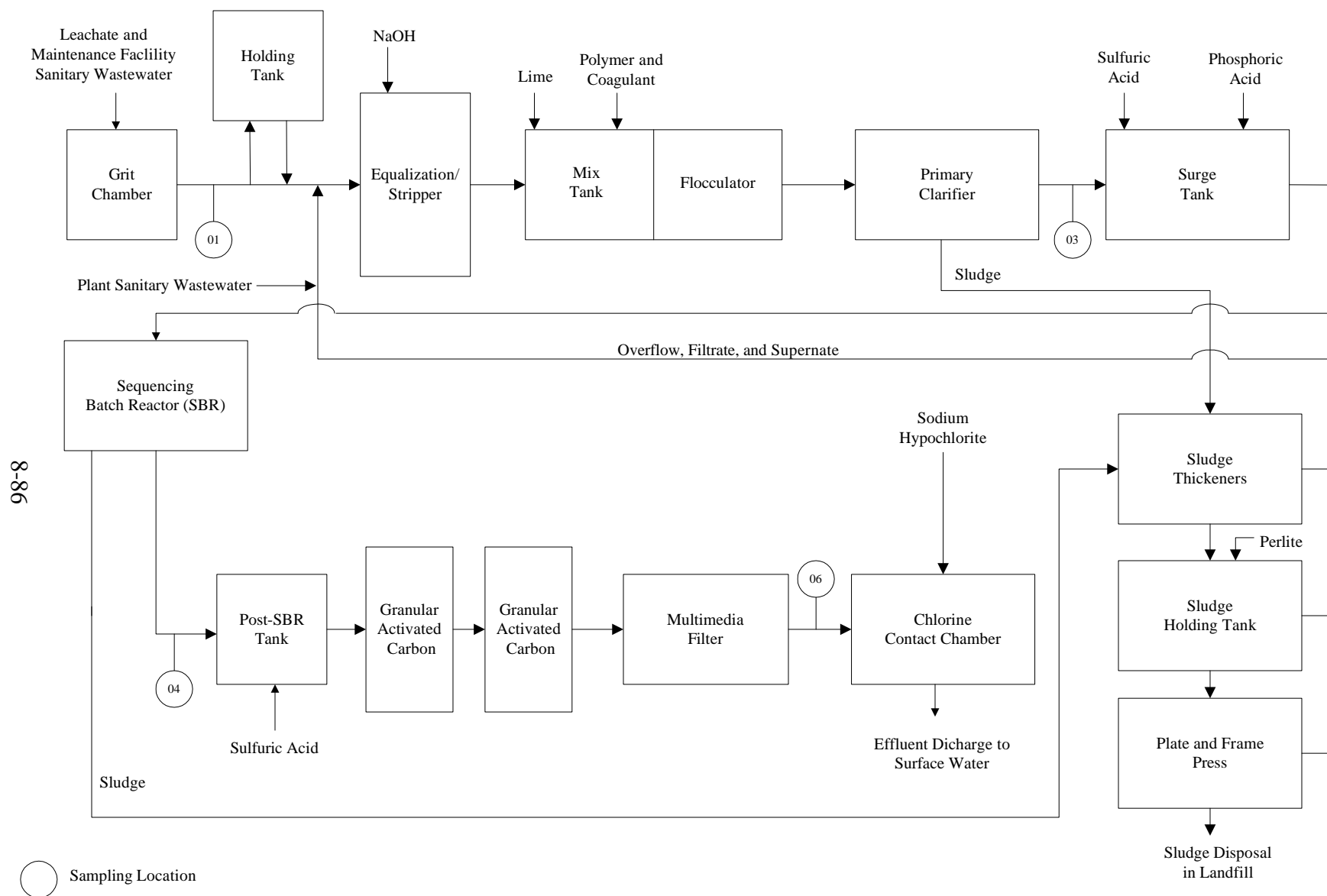[Sludge Thickening] → [Filter Press] → To Hazardous Waste Incinerator

Filtrate

( ) Sampling Location

Figure 8-28: EPA Sampling Episode 4721 - Landfill Waste Treatment System Block Flow Diagram with Sampling Locations

Ferric Chloride Sulfuric Acid

Ferrous Sulfate Sodium Hydroxide Cationic Polymer

Sulfuric Acid Phosphoric Acid

01

02

Equalization Tank (feed tank) → **Chemical Precipitation** → **Flocculation** → **Primary Clarifier** → **Neutralization**

Aeration

Sludge

Return Sludge

Leachate **Storage Tank**

03

Secondary Clarifier → **Hold Tank** → **Contact Tank No. 2** → To POTW

Sludge

Waste Sludge

Waste Sludge

Sanitary Wastewater

Sodium Hypochlorite   Air

Sludge Thickener → **Conditioner** → **Filter Press** → Solids to Landfill

Supernate

Filtrate

Contaminated Water

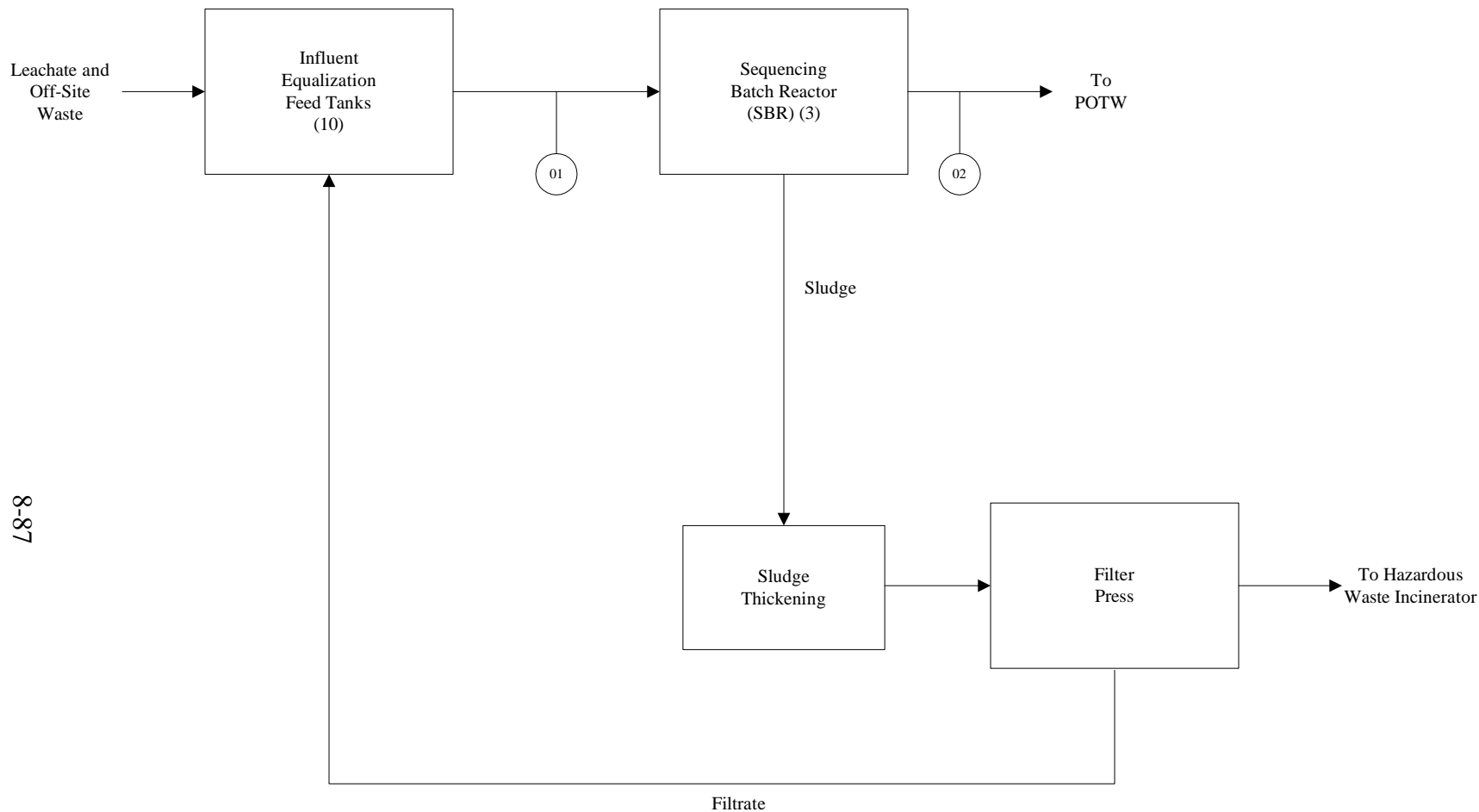Storm Water from Paved Areas → **Contact Water Tank No. 1** ← Clean Water

8-88

○ Sampling Location

Figure 8-29: EPA Sampling Episode 4759 - Landfill Waste Treatment System Block Flow Diagram with Sampling Locations

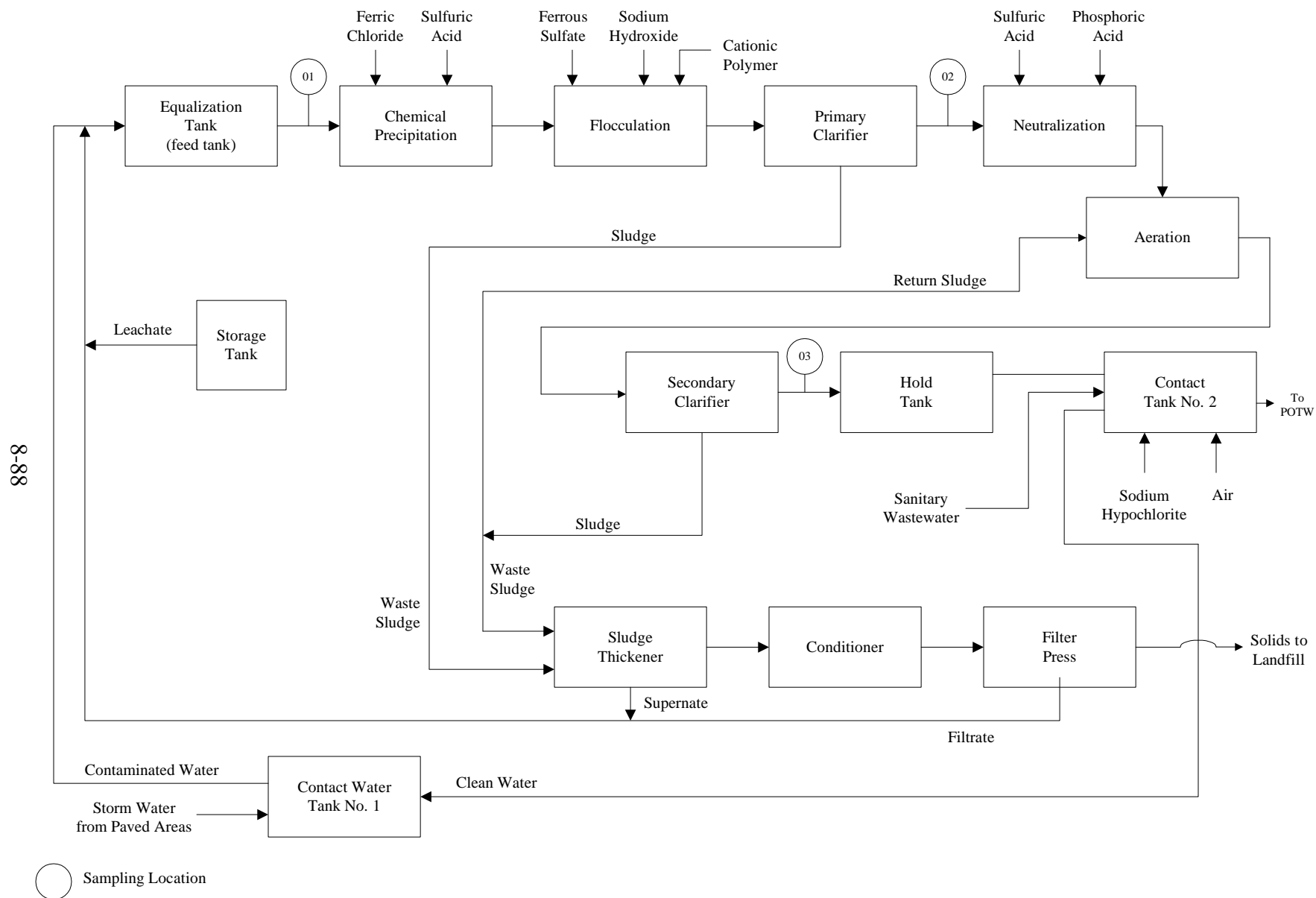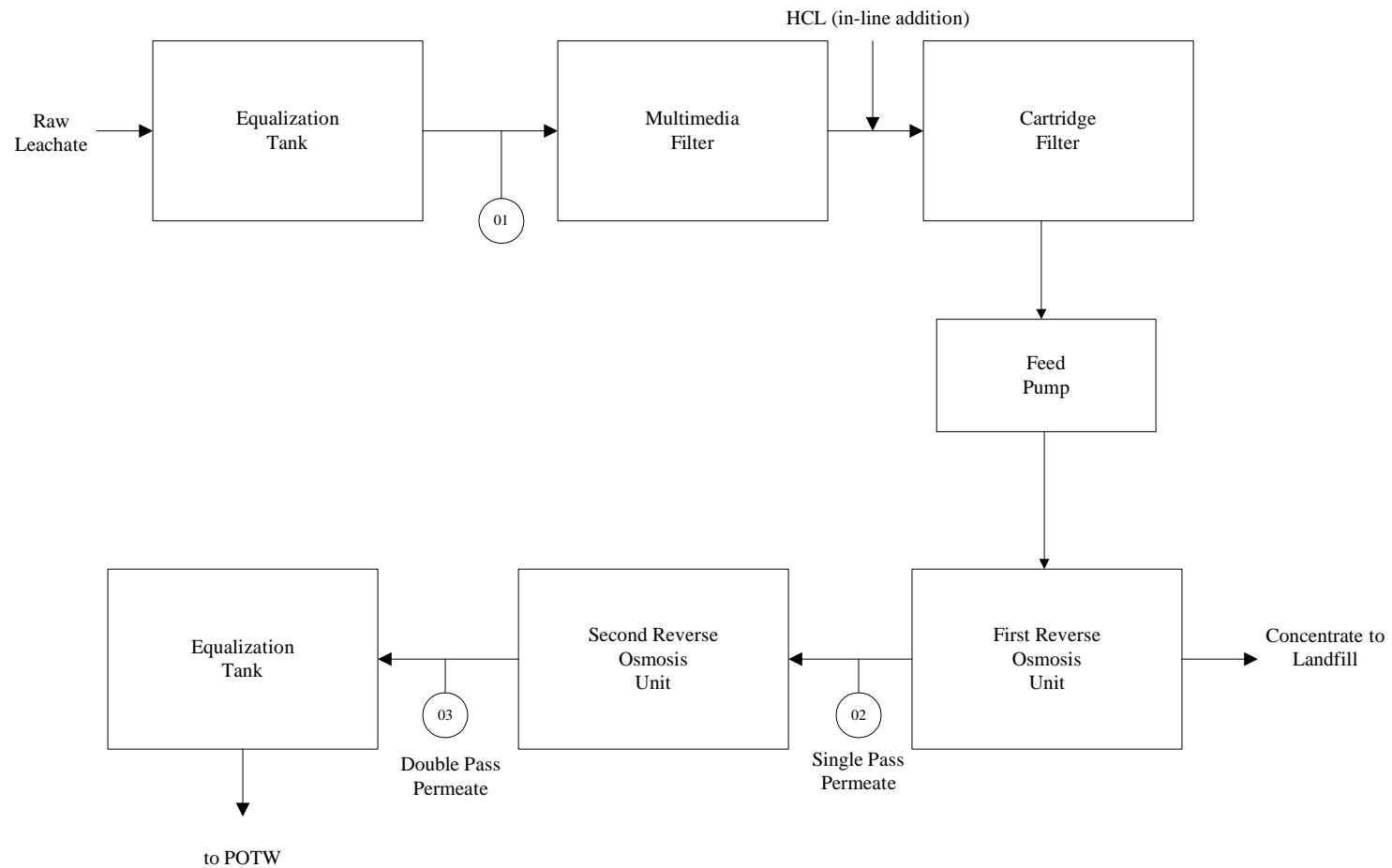HCL (in-line addition)

Raw
Leachate

| Equalization Tank |

01

| Multimedia Filter |

| Cartridge Filter |

| Feed Pump |

| First Reverse Osmosis Unit |

Concentrate to Landfill

02

Single Pass Permeate

| Second Reverse Osmosis Unit |

03

Double Pass Permeate

| Equalization Tank |

to POTW

◯ Sampling Location

Figure 8-30: EPA Sampling Episode 4687 - Landfill Waste Treatment System Block Flow Diagram with Sampling Locations